Casey Bean, Jens Bennedsen, Kristina Edström, Ron Hugo, Janne Roslöf, Robert Songer & Tomohito Yamamoto (eds.)

The 14th International CDIO Conference

Proceedings - Full Papers

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Editorial

The CDIO approach is an innovative educational framework for producing the next generation of engineers. The aim is an education that supports students in the acquisition of strong technical fundamentals while simultaneously developing the necessary professional skills required of a practicing engineer. This is done by providing students with dual-impact learning experiences that are based upon the lifecycle of an engineering project, the Conceiving – Designing – Implementing – Operating (CDIO) of real-world products, processes, and systems. Throughout the world, more than 150 institutions have adopted CDIO as the framework of their curriculum development.

The Annual International Conference is the main meeting of the CDIO Initiative and it includes presentations of papers as well as special seminars, workshops, roundtables, events and activities. The 14th International CDIO Conference takes place in Kanazawa, Japan, June 28 – July 2, 2018, hosted jointly by Kanazawa Institute of Technology and International College of Technology, Kanazawa. The organizers together with the city of Kanazawa welcome you to the event!

The main theme of this year is *Innovations in Engineering Education*. It is visible in the keynote presentations, paper presentations, roundtables and workshops. The rich topical program will facilitate lively discussion and contribute to further advancement of engineering education.

The conference includes three types of contributions: Full Papers, Learning Objects, and Projects in Progress. The Full Papers fall into three tracks: Advances in CDIO, CDIO Implementation, and Engineering Education Research. All contributions have undergone a full single-blind peer review process to meet scholarly standards. The Learning Objects contributions provide resources for specific teaching and learning activities and describe them in detail. The Projects in Progress contributions describe current activities and initial developments that have not yet reached completion at the time of writing.

Originally, 195 abstracts were submitted to the conference. The authors of the accepted Full Paper, Learning Objects, and Projects in Progress abstracts submitted 114 Full Paper manuscripts to the peer review process. During the review, 401 review reports were filed by 85 members of the 2018 International Program Committee. Acceptance decisions were made based on these reviews. The reviewers' constructive remarks served as valuable support to the authors of the accepted papers when they prepared the final versions of their contributions. We want to address our warmest thanks to those who participated in the rigorous review process.

This publication contains the 80 accepted Full Paper contributions to be presented at the conference, of which 4 are Advances in CDIO, 65 are CDIO Implementation, and 11 are Engineering Education Research. These papers have been written by 256 different authors representing 25 countries. This book is available as an electronic publication only. In addition to the Full Papers, 1 Learning Objects contribution and 33 Projects in Progress contributions are to be presented at the conference and are not included in this publication.

We hope you find these contributions valuable for your own research, curriculum development, and teaching practice, ultimately furthering the engineering profession. We also hope that you benefit through the truly unique community of practice that exists within the CDIO Initiative. More than 100 institutions from 32 countries, representing 6 continents, will be present at the conference. Seize the opportunity to discuss and share with colleagues, as global awareness and partnerships are of major importance in the education of the next generation of engineers.

Wishing all of you a wonderful CDIO 2018 experience!

Kanazawa, June 6, 2018

Casey Bean

Jens Bennedsen

Kristina Edström

Ron Hugo

Janne Roslöf

Robert Songer

Tomohito Yamamoto

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RELEVANCE OF CDIO TO INDUSTRY 4.0 – PROPOSAL FOR 2 NEW STANDARDS

Sin-Moh Cheah

School of Chemical & Life Sciences, Singapore Polytechnic

Helene Leong

Department of Educational Development, Singapore Polytechnic

ABSTRACT

This is a paper meant for discussing if the CDIO Framework remains relevant today, considering the manufacturing landscape which is broadly captured under the umbrella of Industry 4.0. It explores if the 12 CDIO Standards need to be expanded to include additional standards. This paper can be broadly divided into 2 parts. The first half of the paper begins with a brief explanation of what Industry 4.0 is, and the key elements such as Internet of Things (IoT), cloud computing, big data and data analytics, and cyber-physical system (CPS). Then, based on the reviews of available publications to date, the paper summarises the implication of Industry 4.0 on the knowledge needed and skill profile of future engineering graduates. This first half concludes with a discussion of how Education 4.0 – the educational 'counterpart' of Industry 4.0 – will affect the learning experience. The second half of the paper reviews the relevance of the CDIO Syllabus in terms of its coverage of knowledge and skills needed for Industry 4.0; followed by the review of the CDIO Standards. Each Standard is studied in relation to its applicability to Industry 4.0. This paper suggests that the CDIO Syllabus be retained in its current format but recommends that one uses a Skills Profile approach when validating the skills and attributes with key stakeholders. The paper also concludes that the CDIO Standards are still relevant as their descriptions can be expanded to reflect the coverage of Industry 4.0. However, to better serve the educational needs of Industry 4.0, this paper proposes that two additional standards be introduced: one on Industry Engagement, and another on Workplace Learning.

KEYWORDS

Engineering Education, Industry 4.0, Internet of Things, CDIO Syllabus and Standards

<u>NOTE</u>: Singapore Polytechnic uses the word "courses" to describe its education "programs". A "course" in the Diploma in Chemical Engineering consists of many subjects that are termed "modules"; which in the universities contexts are often called "courses". A teaching academic is known as a "lecturer", which is often referred to a as "faculty" in the universities.

INTRODUCTION

The main role of the 12 CDIO Standards is to serve as a guideline for educational program reform and evaluation, create benchmarks and goals with worldwide application, and provide a framework for continuous improvement. Recently, Malmqvist, Edstrom & Hugo (2017) proposed a set of 7 potential optional standards, which are suggested for a more advanced or broadened competence. The authors made it clear that the intent is to stimulate discussion to the use of CDIO as framework for redesigning engineering curriculum. They noted that the proposal “should be considered as first drafts, to be further evaluated and refined through discussions in the CDIO Initiative prior to acceptance.” Earlier, Campbell & Beck (2010) had suggested a standard on internationalization and mobility, but was not accepted at that time.

This paper aims to contribute to that discussion. The key difference in our approach here is that we based our reviews on the continued relevance of the existing 12 standards and the syllabus in relation to the new manufacturing landscape broadly captured under the umbrella of Industry 4.0. In particular, we strive to re-interpret the applicability of the existing 12 Standards by viewing them through the lens of Industry 4.0 in meeting the competencies required in Industry 4.0. Our approach is to first carry out review of available publications on the impact of Industry 4.0 on engineering education, and the approach to redesign the engineering curriculum. To this end, we search the Internet using Google Scholar and ScienceDirect. One observation we noted is the lack of publications on educational response to Industry 4.0. Motyl, et al (2017) had noted that currently there are limited studies in engineering education on the educational needs of students. Likewise, Lu (2017) reported of limited systematic and extensive review of recent research on Industry 4.0. As such, this work made references to mostly white papers and reports produced by consulting companies, supported by relevant journal papers and conference presentations.

WHAT IS INDUSTRY 4.0?

Industry 4.0, or “Smart Industry”, or “Smart Manufacturing”, or the Fourth Industrial Revolution, comprising a confluence of trends and technologies, promises to reshape the way things are manufactured. It started in 2011 in Germany as “Industrie 4.0”: an initiative comprising representatives from business, politics, and academia to strengthen the competitiveness of the German manufacturing industry. Industry 4.0 represents a paradigm shift from “centralized” to “decentralized” production, made possible by technological advances which constitute a reversal of conventional production process logic. Simply put, it means that industrial production machinery no longer simply “process” the product, but that the product communicates with the machinery to tell it exactly what to do (GTAI, 2014). The major consultancies tend to define Industry 4.0 to suit their approach of assisting clients make transition from current manufacturing conditions to that of Industry 4.0. While there are broad agreements in terms of its underlying principles such as interoperability virtualization, decentralization, modularity (Hercko & Hnat, 2015), each consultancy appear to have its own interpretation of that components made up Industry 4.0. This is perhaps not entirely surprising. As noted by Pereira & Romero (2017), despite the increased attention on Industry 4.0 by various sectors, the concept remains non-consensual.

From the author’s point of view, and for the purpose of this paper, it is more important to understand the wider implications that Industry 4.0 can affect engineering education, based on the way it impacted the manufacturing industries. It is claimed that companies that adopted Industry 4.0 to transform their manufacturing processes stands to benefit from its many advantages including much greater efficiency, agility and mix in a production without sacrificing quality, cost, or speed; to allow a company to innovate more rapidly and gain greater revenues. However, while progress had been made by some manufacturers, many others are still holding back. Many of the examples in Industry 4.0 appears to be related to process automation in the manufacturing sector (VDMA, 2016; McKinsey, 2017). Indeed, it was noted that while most manufacturers are certainly investing into Industry 4.0 capabilities and technologies, few have achieved the scale and integration required to drive enterprise value from Industry 4.0 (KPMG, 2017). Among the implementation barriers identified, are: lack of necessary talent and challenges with integrating data from disparate sources in order to enable Industry 4.0 applications (EEF, 2016; McKinsey, 2016). These are the areas where engineering education can play a big role in preparing the right type of graduates needed.

INDUSTRY 4.0: WHAT ARE THE KNOWLEDGE AND SKILLS NEEDED?

While domain knowledge remains important, engineers of tomorrow need to also be acquainted with key elements that make up Industry 4.0, which include the Internet of Things (IoT), cloud computing, big data and data analytics, and cyber-physical system (CPS). Again, different consultancies interpret these differently, and an example from one of them is shown in Figure 1. The main idea of the concept is the interconnectivity of production machinery, machined products and semi-finished products and all other systems and subsystems of an industrial enterprise.

For the interest of the wider audience, the following paragraphs briefly describe some of these technologies, as distilled from various publications reviewed.

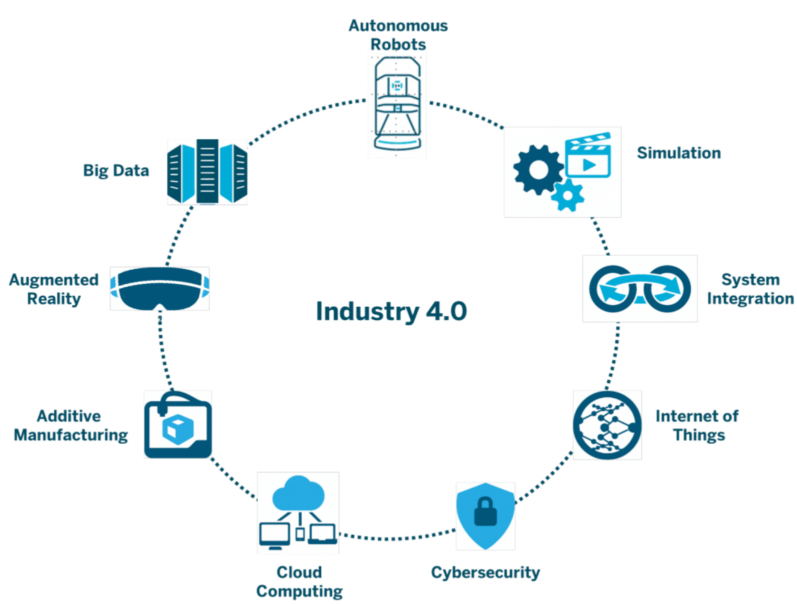

Figure 1. Industry 4.0 and enabling technologies (Source: www.aethon.com)

IoT describes a system where items in the physical world, and sensors within or attached to these items, are connected to the Internet via wireless and wired connections. Each sensor will monitor and collect data on a specific condition such as location, vibration, motion, temperature and other parameters. These sensors can use various types of local area connections such as RFID, Wi-Fi, Bluetooth, etc. Sensors can also have wide area connectivity such as GSM, 3G, and LTE. IoT can connect both inanimate and living things, and change the types of item communicate over a network. With IoT all equipment will have the ability to communicate, share information about their condition and the surrounding environment with people, software systems and other machines. This information can be shared in real-time or collected and shared at defined intervals. Going forward, everything will have a digital identity and connectivity, which means you can identify, track and communicate with objects.

Closely related to IoT are digitization, big data, cloud computing and data analytics. Digitization is the process of converting data from the sensors into a digital format. Digitizing data makes it easier to preserve, access, and share. Big data is a term that describes the large volume of data characterized by volume, velocity, variety, variability and complexity – both structured and unstructured – that inundates a business on a day-to-day basis. The most important thing is what organizations do with the data that matters. Cloud computing, simply put, is the delivery of computing services – servers, storage, databases, networking, software, analytics, and more – over the Internet ("the cloud"). Cloud computing and IoT both serve to increase efficiency in our everyday tasks, and the two have a complimentary relationship: IoT generates massive amounts of data, and cloud computing provides a pathway for that data to travel to its destination. Data analytics refers to qualitative and quantitative techniques and processes used to convert big data into actionable insights that enhance productivity and produce business gain. Data analytics can help generate meaningful production management information that aid decision-making, e.g. make sense of market developments and customer behaviour to improve products and develop new products and services, improve operations, etc (BCG, 2015; Deloitte, 2015).

CPS are enabling technologies which bring the virtual and physical worlds together to create a truly networked world in which intelligent objects communicate and interact with each other. CPS provide the basis for the creation of an IoT, which combines with the Internet of Services to make Industry 4.0 possible. They permit multiple innovative applications and processes a reality as the boundaries between the real and virtual worlds disappear. As such, they promise to revolutionize our interactions with the physical world in much the same way that the internet has transformed personal communication and interaction.

Industry 4.0 is transforming the future of work, creating far-reaching impact on jobs, ranging from significant job creation to job displacement, and from heightened labour productivity to widening skills gaps (WEF, 2016). Existing jobs are also going through a change in the skill sets required to do them. It will create disruptions in the labour market by eliminating some of the low-skilled and/or repetitive jobs, at the same time increasing the shortage of talented and highly-skilled workers (BCG, 2015). Entire manufacturing processes will change, and so is the interaction between human workers and the machines and processes. Such transformation came about as a result of two trends (ISRA & Acatech, 2013): Firstly, traditional manufacturing processes characterised by a very clear division of labour will now be embedded in a new organisational and operational structure where they will be supplemented by decision-taking, coordination, control and support service functions. Secondly, it will be necessary to organise and coordinate the interactions between virtual and real machines, plant control systems and production management systems. There is now convergence of info-communication technologies, manufacturing and automation technology and software.

What about skills needed to realise the objectives of Industry 4.0? Most literatures tend to focus on the benefits of adopting Industry 4.0; and many consultancies are offering advice on the approach to bring out the necessary transformation in business practices to reap the benefits. What are the skills needed and how to develop them are not clear. The next paragraph provides a brief summary of the literatures on skills suggested for Industry 4.0.

Javier (2015) for example, highlighted 4 skills that will help engineers compete and deliver in an age of *smart manufacturing:* systems thinking, data savviness, collaboration and communication, and adaptability. Focusing on robotics and automation, Richert et al (2016) suggested that the needed soft skill competencies will be the ability to solve problems by virtual teamwork and to be able to work in hybrid teams consisting of human and robots, working indispensable together. Benesova & Tupa (2017) suggested qualifications and skills needed for 2 job profile: IT and Production. VDI & ASME (2015) suggested a tiered approach to derive qualifications and skills needed for the factory worker of the future. ILO (2014) suggested using technology foresights for identifying future skills needs and proposed a methodology for skills needs prognosis based on technology roadmaps. KPMG (2016) noted that, since many disciplines are needed for Industry 4.0, a profiling approach based on the convergence of (1) Theoretical knowledge and expertise, (2) Hardware skill, and (3) Software and algorithm skills, would be suitable, as shown in Figure 2. Indeed, technological advancement brought about by Industry 4.0 is impacting all disciplines, economies and industries, perhaps none more so than production, including how, what, why and where individuals produce and deliver products and services (WEF, 2017).

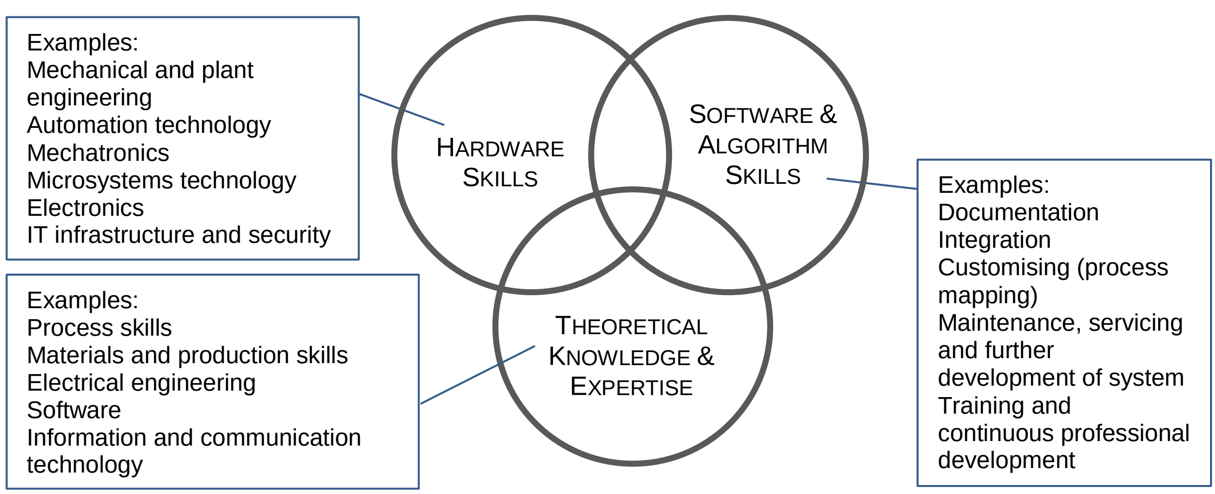

Figure 2. Industry 4.0 Skill Profile (Adapted from KPMG, 2016)

EDUCATION 4.0 – HOW WILL INDUSTRY 4.0 AFFECT ENGINEERING EDUCATION?

Industry 4.0 needs to be supported by Education 4.0: educational institutions need to rethink existing ways of educating learners and how to encourage life-long learning in order to succeed in this latest round of industrial revolution. It can be expected that Industry 4.0 will affect engineering educational systems in the most fundamental ways, including how students are currently engaged. Education is increasingly becoming “just in time” rather than “just in case” (Brophy, 1993): it is more about what you need to know for a certain time than compiling knowledge that may never be needed. Data regarding student performance, behaviour, development, and interaction inside classrooms and online platforms can offer valuable opportunities to improve the learning process. The ability of higher education institutions to leverage on data analytics to exploit such data to produce useful insights would result in intelligent decisions with regards to the delivery of customized education and personalized learning experience for students. The learning cycle will also be affected, for example, shorter in-campus learning to make room for longer internship without extending program duration.

Educational institutions will need to offer more short courses, targeting at adult learners seeking new knowledge and skills as part of lifelong learning and as preparation for career advancement. It is highly unlikely that employees will get days-off for long duration to attend lessons full-time (e.g. a semester) in classrooms for a whole semester as per current academic calendars. Shift workers will certainly pose additional challenges. Successful skills development for Industry 4.0 cannot be delivered solely through "traditional" training and professional development formats such as face-to-face learning. It increasingly requires the use of new digital formats targeted at specific learner groups and needs. It can be anticipated that greater usage of blended classroom and immersive virtual learning environments (VLEs) will be the norm. All these in turn, will change the way teaching is done, and how teachers are trained, especially in their digital literacy, which include not only the design of VLE but also in digital coaching and virtual collaborations (Richert, et al, 2015).

Lastly, we noted that a key component in engineering education is project work. Projects in Industry 4.0 will be increasingly complex and multi-disciplinary in nature. For example, the innovation and development of CPS will require computer scientists and network professionals to work with experts in various disciplines as well as in globalized contexts (Richert, et al, 2016). Students need to be more proficient in interpersonal skill, in working with people with different background and disciplines from their own. The Learning Factory concept, originally introduced in 1994 (Abele, et al, 2015), is now gaining popularity as a way to teach students about working under the Industry 4.0 environment (Baena, et al, 2017; Erol, et al, 2016).

From the above discussion it is clear that a new curriculum is needed for Industry 4.0, to prepare a new generation of engineers who can integrate multi-disciplinary and cross-domain knowledge, and able to focus more on understanding the working of system from a systems perspective than merely being an expert on a deeply topical domain of knowledge. These engineers have to cope with new paradigms and concepts (e.g. modelling, simulation, inter-operability and self-organization) and emergent technologies (e.g. IoT, big data and data analytics). Thus, the challenge is to develop and design new curricular programs that focuses such multi-disciplinary specialization, which apparently is contradictory: on one hand to have understanding over a wide plethora of topics and technologies, which can be provided by Bachelor and Master programs, and on the other hand to have short term learning and training programs on specific topics that provide specialization (Leitao, 2017).

While various authors had suggested what an engineering curriculum in Education 4.0 should contain, e.g. Onar et al (2018); FICCI-EY (2017); Coskun, et al (2016); Lorenz, et al (2015); there is still a lack of good framework for which to review an existing curriculum or to design a new curriculum. Although not written specifically to address the challenge of Industry 4.0, Kemp (2016) had provided an excellent review of how engineering education can change to adopt to the challenges in a VUCA (volatile, uncertain, complex, ambiguous) world with a vision for engineering education with 8 key aspects: (1) rigour of engineering knowledge, (2) critical thinking and unstructured problem solving, (3) interdisciplinary and system thinking, (4) imagination, creativity, initiative, (5) communication and collaboration, (6) global mind-set: diversity and mobility, (7) ambitious learning culture: student engagement and professional learning community, and (8) employability and lifelong learning. On the other hand, the CDIO Framework had been widely used since its introduction in 2001. The question we asked is: Can the CDIO Framework be used to aid curriculum review and design under Industry 4.0?

COMPARING CDIO FRAMEWORK WITH INDUSTRY 4.0

The previous sections noted that currently there is a lack of framework addressing educational needs to meet the requirements of Industry 4.0. As noted by Kiel (2017), the lack of research in this area can be attributed to the technical core of Industry 4.0; and hence most works are currently focused on technical challenges and enablers. As collaborators in CDIO, we are interested in finding out if the CDIO Framework that we had adopted for almost 10 years can still serve its purpose of guiding us in the redesign of our engineering curriculum.

We first look at the CDIO Syllabus. The initial syllabus was written in 2001 (Crawley, 2001) with a recent update in 2011, in part to add missing skills and in part to clarify nomenclature to make the Syllabus more explicit and consistent with national standards (Crawley, et al, 2011). We noted that new knowledge required by Industry 4.0 can be effectively covered in Part 1 Disciplinary Knowledge and Reasoning of the CDIO Syllabus v2.0, which is meant to be a placeholder for more detailed description of disciplinary fundamentals necessary for any particular field of engineering. Topics on IoT, CPS, Cloud Computing, Data Analytics, etc can all be covered in Part 1. As Crawley (2001) aptly reminded: “The placement of this item at the beginning of the Syllabus is a reminder that the development of a deep working knowledge of technical fundamentals is, and should, be the primary objective of undergraduate engineering education.”

Unlike Part 1, the remainder of the Syllabus (i.e. Parts 2, 3 and 4) is still common to all engineering professions. Engineers of all types use approximately the same set of personal and interpersonal skills, and follow approximately the same generalized processes. This is a neat arrangement as it allows educational institutions adopting the CDIO Framework to customize the programs to include new knowledge brought about by Industry 4.0 into the CDIO Syllabus without altering the overall general format of the document. As such, we conclude the present CDIO Syllabus has sufficiently captured all the skills needed for Industry 4.0.

Next, we noted that Parts 2, 3 and 4 of the CDIO Syllabus is presented as itemized entries. Within each part, the skills and attributes are further organized into sub-categories down to X.X.X.X level. The number of entries had grown somewhat from version 1.0 to version 2.0. We face some challenges when carrying out validation exercise of the required skill sets with key industry stakeholders. Significant amount of time needs to be invested to ‘educate’ our industry counterparts firstly on the CDIO Syllabus in general, and secondly on the knowledge underpinning each skill. The inter-relatedness of different skills and attitudes also posed problems for them. We also noted that different industry will likely adopt Industry 4.0 in varying degrees (IndustriALL, 2017). Leading the field is industrial engineering and process automation, which see widespread implementation of various Industry 4.0 solutions on the factory floor. The chemical processing industries, on the other hand, already employed extensive process control and management system in its daily operations, and may see more Industry 4.0 applications in streamlining operations across its entire value chain. The skills and attributes needed of process technicians in the chemical processing industry may not have changed much, compared to one involved in process automation at the shop floor. It is therefore paramount that program owners seek validation with industry stakeholders on the revised educational goals in any redesigned curriculum. We find that the Skills Profile approach mentioned in earlier section (see Figure 2) is a more useful and manageable approach for the validation process, and would like to suggest that a review be undertaken by suitable CDIO Collaborators. Program designers should cluster key competencies and proficiency level based on a person's job roles in a given job function. The same approach is used by other organizations such as OECD in their competency framework (OECD, 2014).

We next turn our attention to the CDIO Standards. Using the information from our review of Industry 4.0 and its implications on engineering education covered previously, we set off studying the CDIO standards one by one, carefully reviewing each standard's "Description" and "Rationale", and view them through the lens of Industry 4.0 to ascertain the relevancy of each standard. Where deem appropriate, each "Description" and "Rationale" is reinterpreted with specific reference to key topics in Industry 4.0. The outcomes are shown in Table 1 below. Each CDIO Standard and its brief explanatory note are shown in grey boxes, and the relevance of that standard to Industry 4.0 is presented below the grey boxes, with brief explanations highlighting how the standard can embrace elements of Industry 4.0.

Table 1. Evaluation of CDIO Standards vis-à-vis Industry 4.0

<table>
<tr><td>CDIO Standard 1 – The Context</td><td>Adoption of the principle that product, process, and system lifecycle development and deployment -- Conceiving, Designing, Implementing and Operating -- are the context for engineering education</td></tr>
<tr><td colspan="2">Relevance to Industry 4.0:
This clearly remains relevant in the context of Industry 4.0, but with the new emphasis on the importance of working in multi-disciplinary teams; as the nature of product, process or system will be different, and so is the lifecycle development and deployment, which is likely to be shorter. An example is in the field of biomedical devices.</td></tr>
<tr><td>CDIO Standard 2 – Learning Outcomes</td><td>Specific, detailed learning outcomes for personal and interpersonal skills, and product, process, and system building skills, as well as disciplinary knowledge, consistent with program goals and validated by program stakeholders</td></tr>
<tr><td colspan="2">Relevance to Industry 4.0:
As noted in the review of relevance of CDIO Syllabus, the learning outcomes covered in the CDIO Syllabus remain relevant, but validation with relevant stakeholders is of utmost importance, and suggested (see main text) a review of the process using a Skills Profile approach instead of rating each skill one by one.</td></tr>
<tr><td>CDIO Standard 3 – Integrated Curriculum</td><td>A curriculum designed with mutually supporting disciplinary courses, with an explicit plan to integrate personal and interpersonal skills, and product, process, and system building skills</td></tr>
<tr><td colspan="2">Relevance to Industry 4.0:
Under this Standard, new knowledge of topics in Industry 4.0 such as Internet of Things (IoT) and data analytics should be covered in suitable module(s), the depth of which depends on the needs of each engineering discipline and year of study. For example, specific information on performance of critical equipment (e.g. catalytic reactors) can be a cursory introduction to IoT for Year 2 chemical engineering, while detailed data analytics is a needed competency in a course on cyber security or consumer behaviourism. Likewise, skills such as virtual collaboration should be integrated into suitable module(s) to develop the required competence over the duration of study.</td></tr>
</table>

Table 1. (Cont'd)

<table>
<tr><td>CDIO Standard 4 – Introduction to Engineering</td><td>An introductory course that provides the framework for engineering practice in product, process, and system building, and introduces essential personal and interpersonal skills</td></tr>
<tr><td colspan="2">Relevance to Industry 4.0:
Following up on the point made in Standard 3, all engineering programs should expose students to an introduction of Industry 4.0 and the role it plays in the industry. This could be a modification of existing cornerstone (basic-level) project exercise with the added dimension of Industry 4.0, such as exposure to big data and usefulness of data analytics for example, along with personal and interpersonal skills such as digital literacy, time and resource management.</td></tr>
<tr><td>CDIO Standard 5 – Design-Implement Experiences</td><td>A curriculum that includes two or more design-implement experiences, including one at a basic level and one at an advanced level</td></tr>
<tr><td colspan="2">Relevance to Industry 4.0:
It had to be acknowledge that existing curriculum for almost all engineering education is already very congested. Hence, we do not advocate adding another project to students' capstone (advanced-level) experience. Instead, program owners should carefully review offering of existing projects that involve applications of ideas from Industry 4.0. In this regard, program owners should work collaboratively with the industry it is serving to obtain more industry-related projects for students. Multi-disciplinary projects should be encouraged to the extent possible. At this level, students should be able to demonstrate competence in various CDIO skills, including new skill sets required in Industry 4.0.</td></tr>
<tr><td>CDIO Standard 6 – Engineering Workspaces</td><td>Engineering workspaces and laboratories that support and encourage hands-on learning of product, process, and system building, disciplinary knowledge, and social learning</td></tr>
<tr><td colspan="2">Relevance to Industry 4.0:
Consistent with the focus on Industry 4.0 in Standard 5, the notion of Engineering Workspaces should expand beyond the school campus. With Industry 4.0 this should include the shop floor, factory compounds, and processing plants where students complete their internships or industrial attachments. In addition, engineering workspaces should also embrace virtual spaces (virtual learning environments, or VLEs) as well, especially in areas of Augmented Reality and Virtual Reality (AR/VR) where students learn via simulation. Such workplaces, especially virtual ones, can strengthen the 'hands-on' learning with 'minds-on' learning as well, for example, with the AR/VR environment students can try various combinations of possible product, process or system that would be too cost-prohibitive to do with physical items.</td></tr>
<tr><td>CDIO Standard 7 – Integrated Learning Experiences</td><td>Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal and interpersonal skills, and product, process, and system building skills</td></tr>
<tr><td colspan="2">Relevance to Industry 4.0:
As is the case for Standard 6, collaborating in an online environment such as the cloud, can help foster development of personal and interpersonal skills, and complement the effort in the classroom where face-to-face interactions are taking place. The AR/VR environment can provide a more authentic yet safe experiential learning environment that can better facilitate the acquiring of new skills such as troubleshooting a process the runs the risk of turning hazardous (see also Standard 8 below). An affordance of Industry 4.0 is that it enables the simulation of work environment that goes on 24/7 that suits the work cycle of adult learners.</td></tr>
</table>

Table 1. (Cont'd)

CDIO Standard 8 – Active Learning	*Teaching and learning based on active experiential learning methods*
Relevance to Industry 4.0: Cloud, IoT, immersive environment in AR/VR etc all bring about opportunities to engage in active, experiential learning in a new way; especially in terms of online collaboration among peers, or in carrying out (simulated) real world tasks such as emergency response to a chemical accident, that otherwise will be too expensive or dangerous to carry out in campus setting. This also means that higher order thinking skills (exploring different scenarios or outcomes) can be better inculcated. The current active learning methods such as think-pair-share, one-minute paper, etc are still very relevant; but they be made more effective by creative use of technology, notably via the EdTech tools.	
CDIO Standard 9 – Enhancement of Faculty Competence, and	*Actions that enhance faculty competence in personal and interpersonal skills, and product, process, and system building skills*
CDIO Standard 10 – Enhancement of Faculty Teaching Competence	*Actions that enhance faculty competence in providing integrated learning experiences, in using active experiential learning methods, and in assessing student learning*
Relevance to Industry 4.0: The changes in ways that learning can take place under Industry 4.0 as discussed in earlier sections require that lecturers adapt their teaching to suit the new learning environment. Lecturers need to learn new ways to engage students via the cloud, EdTech tools, use of AR/VR, etc. They need to integrate new skills identified in Industry 4.0 into the modules they are teaching. Lecturers also need training on how to use data analytics to obtain real-time analysis of students learning experience, and devise corrective actions as necessary. Skills in digital coaching and joint problem-solving in virtual world will be needed. Lastly, lecturers need to update their knowledge in how Industry 4.0 is affecting the industry their program is serving. This requires careful planning for staff industrial attachment especially in times of manpower crunch.	
CDIO Standard 11 – Learning Assessment	*Assessment of student learning in personal and interpersonal skills, and product, process, and system building skills, as well as in disciplinary knowledge*
Relevance to Industry 4.0: Just as Industry 4.0 affect the ways students learn, it will also affect the ways assessments are carried out. For example, the affordances of data analytics will bring about changes in the way students are assessed. More focus can be directed towards formative assessment when data are available in real-time to address specific learning challenges (such as misconceptions, wrong assumptions) encountered in class. Higher-order or more challenging assessments can be carried out based on real-world "What-If" scenarios (see Standard 8) based on simulated emergency situations in AR/VR.	

Table 1. (Cont'd)

CDIO Standard 12 – Program Evaluation	*A system that evaluates programs against these twelve standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement*
Relevance to Industry 4.0: This standard will always be relevant as it relates to continual improvement. As noted in Standard 1, and in the main text, adoption of Industry 4.0 will differ from industry to industry, and so are the skill sets. Furthermore, it can be expected that advancement in technology will further influence the development of new skills. Hence it is of paramount importance that the program be evaluated regularly, for example, within 3 years instead of the more commonly accepted period of 5 years.	

In summary, our comparison of the CDIO Syllabus and Standards showed that the CDIO Framework is still relevant to Industry 4.0. However, the required curriculum and the way learning that will take place in the future will be quite different. More specifically, the curriculum need to broader to offer more opportunities for multi-disciplinary project work, and cross-linking subjects such as data analytics or CPS via free electives. These subjects may even be delivered by industry professionals, who possess the latest technical know-how is this fast-changing area. Also, more learning will increasingly be realized at the workplace itself, such as via internships lasting 6 months or longer. Achieving these will require program owners to actively engage the relevant industry partners.
To this end, we opined that existing standards may fall short in 2 areas – one is the need for educational institutions to more actively engage key stakeholders, notably, the potential employers; and another to provide guidance for educational institutions to manage students' learning at the workplace. We therefore propose to introduce 2 new standards as presented in the next section.

RECOMMENDATIONS

The first additional Standard we propose, tentative labelled Standard 13, is that of Industry Engagement, defined as "Actions that education institution undertake to actively engage industry partners to improve its curriculum". The aim of any curriculum revamp is to prepare industry-ready graduates. Some of the learning outcomes stipulated in program aims or articulated in the institution's graduate attributes can only be realistically achieved in real-world work settings. Having supportive industry partners can help to ensure that such learning experiences be delivered to students. Learning in real-world context is meaningful and engaging for students, it not only helps make the connections between what is learnt in campus and what is being practiced in the industry, but can also help improve their understanding of real-world expectations and shape their mind sets, making them life-ready, work-ready and world-ready. The CDIO Standard had been noted to be useful for engagement of industry stakeholders (Male, King & Hargreaves, 2016). The importance of industry engagement is numerous, and it can address the requirements spelt out in most, if not all, of the existing 12 CDIO Standards.

Industry partners play a crucial role in the training of students to be the professionals in their field, for example, by providing them opportunities to experience real-world work environment via industrial attachment or internship (Standards 1, 7). Students can also work on real-world projects while on industry attachment or internship, or in campus working on industry-sponsored projects (Standards 5, 6). Industry partners can serve as judges evaluating the work done by students (Standard 11). Even routine, office-type work is authentic and experiential for students (Standard 8). Industry partners can also complement students' academic studies by taking up teaching role as adjunct professor, as speakers for course seminars, or as members of a program's advisory panel. They can also partner with academic staff to jointly develop curriculum that is directly relevant, up-to-date and useful to the industry. In addition, industry partners can also support the educational institution's continuous professional development program by offering staff placement opportunities for teaching faculty to upgrade his/her technical know-how (Standards 9, 10). Of course, the issue of industry engagement is not new, and it may be argued that industry engagement is already implied in Standard 1 (CDIO as Context) and Standard 12 (Industry partners and stakeholders).

However, we believe that the advent of Industry 4.0 has brought to the fore its importance. We believe that having a new standard specifically aimed at Industry Engagement has its merit, to make explicit the necessity of actively seeking industry feedback not just in designing of our curriculum, but also in delivering them for example through co-teaching and co-supervision of projects.

The second additional Standard we propose, is tentatively labelled Standard 14 Workplace Learning. Traditionally the concept of "learning" has been related to formal education, i.e. in classrooms in educational institutions. Keen interest in workplace learning are now on the rise, driven by unprecedented changes brought about by recent technological development, most recently under the banner of Industry 4.0. The classic work that highlight differences between learning in educational institutions and learning elsewhere (at work, for example) was provided by Resnick (1987). Recent research on the outcomes of education particularly at the tertiary level, has shown that there is gap between the knowledge and skills needed at work and those produced through formal education (Tynjala, 2008). Billet (2014) had long argued that there is no separation between participation in work and learning, as individuals engage in work activities and interactions they learn through that engagement. Workplace learning can enhance in-campus learning by providing students with opportunities to apply classroom knowledge in real-world setting, and in some cases, to deepen that technical capability. It can also add value to the development of desired graduate attributes such as professional and ethical responsibility, appreciation of social, cultural and environmental context of engineering practice, etc – the sorts of abilities that cannot be acquired by sitting in lecture halls.
There had been various definitions of workplace learning, with terms such as work-based learning, work-integrated learning, and work-related learning are all being used in various literatures. Griffith & Guile (2004) for example, suggested a topology of 5 models of work experiences. In the present context, we define workplace learning as "A curriculum that includes students working in a real-world work environment with the aims of strengthening in-campus learning and developing their professional identity."

While there remained many challenges in implementing workplace learning, such as maintaining consistent desired learning outcomes among students attached to different companies, Radcliffe (2002) argued that technological advances had made possible the pedagogical convergence between work-based learning and campus-based learning. Against these developments, we felt that existing CDIO Standards supplemented with a separate standard on workplace learning is warranted to guide faculty in designing a more authentic learning experience for students.

Details of the proposed 2 new standards are shown in Appendix 1, using the "traditional" CDIO template providing a brief description and rationale for the standard, and the corresponding set of rubrics. The definition of Workplace Learning may warrant further clarifications to arrive at a common understanding of the terminology within the CDIO community as well as for potential collaborators. Likewise the suggested rubrics are by no means definitive. We would encourage debate within the CDIO community to refine them using the approach suggested by Bennedsen, et al (2017) when they proposed an updated rubric for the CDIO self-evaluation.

CONCLUSION & FUTURE WORK

This paper provides a brief introduction to Industry 4.0, and shares the outcome of a study of into the relevance of CDIO Framework to Industry 4.0. It concludes that the CDIO Framework – both the Syllabus and Standards – still remains relevant as reference document to guide the redesign of engineering education. For the CDIO Syllabus, it is suggested that the skill sets be validated with key stakeholders using a "Skill Profile" approach rather than itemized listing when the framework was first formulated. For the CDIO Standards, it is suggested that their interpretation be enlarged to embrace specific features brought about by Industry 4.0, notably the real-world learning via industry projects, virtual learning environment and collaboration. Lastly, it is also suggested that 2 new Standards – namely Industry Engagement and Workplace Learning – be introduced.

It is believed that the ideas presented and recommendations given will prove valuable to program owners on how to use the CDIO Framework to revise their curriculum to better prepare graduates for the world of Industry 4.0. In the same spirit as expressed by Malmqvist, Edstrom & Hugo (2017), the authors too, suggest that the proposal in this paper be treated as first drafts, to be further studied by the CDIO community for their merits and acceptance.

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BIOGRAPHICAL INFORMATION

Sin-Moh Cheah is the Senior Academic Mentor in the School of Chemical and Life Sciences, Singapore Polytechnic; as well as the Head of the school's Teaching & Learning Unit. He spearheads the adoption of CDIO in the Diploma in Chemical Engineering curriculum. His academic interests include curriculum revamp, academic coaching and mentoring, and using ICT in education. He has presented many papers at International CDIO Conferences.

Helene Leong is the Director of the Department of Educational Development at Singapore Polytechnic. Her current focus is on the use of technology in education, enhancing students' intrinsic motivation, and the pedagogy for professional formation and identity. She is also the co-leader for the CDIO Asian region.

Corresponding Author

Mr. Sin-Moh Cheah
School of Chemical & Life Sciences,
Singapore Polytechnic
500 Dover Road, Singapore 139651
smcheah@sp.edu.sg

APPENDIX 1 Recommendations for 2 New CDIO Standards

Standard 13 – Industry Engagement

Actions that education institution undertake to actively engage industry partners to improve its curriculum.

Description:

Industry partners play a crucial role is the training of students to be the professionals in their field, for example, by providing them opportunities to experience real-world work environment via industrial attachment or internship (Standard 1, Standard 7). Students can also work on real-world projects while on industry attachment or internship, or in campus working on industry-sponsored projects (Standard 5). Industry partners can also complement students' academic studies by taking up teaching role as adjunct professor, as speakers for course seminars, or as members of a program's advisory panel. Industry partners can also support the educational institution's continuous professional development program by offering staff placement opportunities for teaching faculty to upgrade his/her technical know-how.

Rationale:

The aim of any curriculum revamp is to prepare industry-ready graduates. Some of the learning outcomes stipulated in program aims or articulated in the institution's graduate attributes can be realistically achieved in real-world work settings. Having supportive industry partners can help to ensure that such learning experiences be delivered to students. Learning in real-world context is meaningful and engaging for students, it not only helps make the connections between what is learnt in campus and what is being practiced in the industry, but can also help improve their understanding of real-world expectations and shape their mind sets, making them life-ready, work-ready and world-ready.

Rubric:

Scale	Criteria
5	Industry engagement is institutionalized, and forms part of the program's continual improvement process.
4	Part of the program is developed with industry input, and delivered jointly or severally by industry partners, and reviewed for relevance.
3	An industry review panel has been set up and periodic meetings conducted.
2	Industry partners are occasionally engaged in delivering guest lectures on selected topics in the curriculum, or as adjunct lecturers.
1	The need for industry engagement is recognized and benchmarking study has been planned or in progress.
0	There are no plans or practices to engage industry partners in the program's teaching.

APPENDIX 1 (cont'd)

Standard 14 – Workplace Learning

A curriculum that includes students working in a real-world work environment with the aims of strengthening in-campus learning and developing their professional identity.

Description:

The workplace can be an important place for learning and development, and in which knowledge can be created and skills acquired. In the workplace, the acquisition of knowledge or skills can occur via both formal or informal means. Workplace learning occurs mostly through work-related interactions and is generally described as contributing to the learning of both the individual employee and the organisation as a whole. Learning at the workplace can take place via self-directed learning, networking, coaching and mentoring.

Rationale:

There are limitations on what students can learn within the campus setting. Students may also be "sensitized" to the school environment and not well prepared for the real-world, for example, in exercising of interpersonal skills or decision making on ambiguous issues often with conflicting perspectives. Workplace learning can also help to instill in students greater sense of professional identity and sense of responsibility.

Rubric:

Scale	Criteria
5	Industry attachment or internship programs are structured with clear learning outcomes and jointly formulated with industry partners, and continually reviewed to improve the student learning experience.
4	Longer-term student attachment or internship in place, but without detailed structure for its execution to attain the desired learning outcomes.
3	Students attended short-term (2 to 6 weeks) of industry familiarization program.
2	There are some ad hoc study trips conducted for students to get exposure to the relevant industry.
1	The need for workplace learning is recognized and benchmarking study has been planned or in progress.
0	There are no plans or practices to provide students with opportunities for learning in the relevant industry for which they are trained.

16

THE CDIO FRAMEWORK AND NEW PERSPECTIVES ON TECHNOLOGICAL INNOVATION

Frido Smulders

Faculty of Industrial Design Engineering, Delft University of Technology

Aldert Kamp

Faculty of Aerospace Engineering, Delft University of Technology

4TU.Centre for Engineering Education
Delft, the Netherlands

Clement Fortin

Space Center
Skolkovo Institute of Science and Technology, Moscow, Russia

ABSTRACT

Technological innovation happens on a daily basis all around us. Yet, in our educational programs there is rarely any attention paid to what this is and how this unfolds over time in real life. This is not at all surprising, since there is not one unified and widely accepted body of knowledge on technological innovation that is grounded enough, meaning, knowledge based on research of technological innovation practice. The CDIO-framework is implicitly addressing innovation from the perspective of existing technological knowledge and therefore is not yet equipped enough for the purpose of tech-innovation. This paper therefore aims to initiate a discussion on what technological innovation is and how this could fit within the CDIO-framework. We will provide a definition of technological innovation based on innovation theoretical framework which reaches its readiness when practice is able to apply the new technology to design, engineer, build, maintain and dispose the objects that apply that particular technology. This lens will be used to analyze a well-documented case that reports on the development of a new structural aircraft material that is now widely used in the Airbus A380, hence a technological innovation. It will be shown in this paper that the research activities that support the development of the new technology, follow the logic of innovating as a generic and natural phenomenon. The paper ends by proposing a possible path to bring the subject of technological innovation within the confines of our educational curricula, without too much cutting on the subjects that we are teaching. Its base comes from the idea that what we are teaching today is the result of a technological innovation process of yesterday.

KEYWORDS

CDIO framework, Engineering education, technological innovation, product innovation

INTRODUCTION

This paper provides an additional perspective on the existing CDIO-framework by explicitly focusing on the innovation of technologies. The CDIO-framework advocates conceive-design-implement-operate as the sequence that brings complex products and systems to life in a collaborative setting of involved disciplines. As such, the CDIO-framework aims to teach engineering students what is necessary to become ‘engineers that can engineer’ in the daily practice of organizations. They need an in-depth working knowledge about their discipline, have interdisciplinary skills and understand the process of conceive-design-implement-operate (e.g. Malmqvist, 2017). This framework for engineering education advocates frequent design-build cycles that include a strong focus on teamwork and interpersonal skills, in addition to the deep technical knowledge belonging to the various disciplines. The CDIO-framework is therefore believed to provide a holistic perspective on engineering education that mimics the engineering profession. A profession that by default forms a crucial partner in technological innovation processes.

The CDIO-sequence covers some innovation processes because the conceive-activity covers customer needs, technology enterprise strategy and conceptual technical & business plans (Malmqvist, 2012). The design-activity covers “plans, drawings and algorithms that describe what will be implemented”, and the implement-activity focuses on the “transformation of the design into the product, process, or system” that during the operate-activity is “delivering the intended value” of complex engineering systems (Malmqvist 2012).

We define innovation as ‘changing an existing environment by the introduction of something new’, which is based on the Latin ‘innovare’ (Smulders, 2015). Innovation ranges from incremental to radical changes. Consider for instance the development and market introduction of a new model vacuum cleaner versus the development and delivery to its first customer of Boeing’s Dreamliner. *Incremental innovations* could be defined as new products that apply existing and proven technology. *Radical innovations* make use of new technologies, cutting edge technologies that just passed the threshold of applicability, reliability and safety. Boeing’s Dreamliner is the first passenger plane where the airframe consists of more than 50% composite materials. A radical innovation that to some extent changes the rule of the game by delivering new features to airlines and passengers. Substantial lower operating costs and less maintenance and for passengers more comfort.

As we will further address in this paper, the example of the new model of a vacuum cleaner is representing a large class of what Smulders (2014) termed single-loop innovations, that is new product ideas with existing technology. Very little changes are necessary to absorb the ‘new’ product or system across the value chain, including manufacturers, suppliers, distributors, sellers and users. The second example then forms a much smaller class of double-loop innovations: a new product idea with a new technology. Double-loop innovating activities require many changes for all involved stakeholders, some of these changes could be very drastic or dramatic as the Dreamliner case showed us (e.g. Shenhar et al., 2016).

It is not clear how the development process of products and systems, and the innovation process of technologies are interrelated. Consider for instance the development of new structural materials for the aerospace industry and how composites ended up in the Dreamliner. The first planes that used composite materials were designed by engineers that carried forward the metallic tradition in their engineering process and applied these to the new class of materials (Potter, 2009). The aircraft manufacturing industry for many years used existing knowledge and norms of metallic (aluminium) structures to design parts from carbon fibre, which resulted in what is called "black aluminium" parts (Tsai, 1993), parts made from carbon to replace existing components without realizing the full potential of the new material. In this manner engineers for decades were not able to design in such a way that took full advantage from the inherent material properties of composites.

The development and introduction of Boeing's 787 Dreamliner marked the situation that enough new engineering knowledge was developed to create a passenger plane of which more than 50% of the airframe is made out of composite materials. The fact that the 787 is the first plane that made extensive use of composites indicates that engineers and managers had sufficient confidence that enough validated engineering and manufacturing knowledge was available for developing such an innovative plane. The knowledge had been developed and validated over the past decades by engineering scientists and specialized companies, that is, knowledge located within the scientific domain of universities as well within the practical domain of specialized companies. One could say, the technology was then ready for full scale application. In other words, composite technology had reached the required level of maturity (Level 6, Fig 1) of Technology Readiness Level (e.g. Héder, 2017).

For the purpose of this paper, we define technology readiness from a business innovation perspective: Technologies are ready if companies are able to design, engineer, manufacture, operate, maintain and dispose the artefacts that use that particular technology.

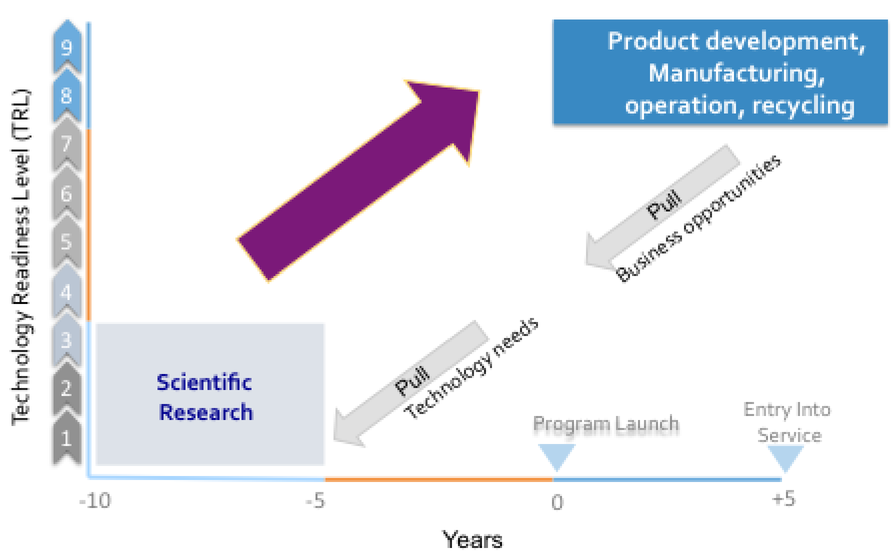

Figure 1: Technology Readiness Levels over time (Fortin).

Back to CDIO: The development of a new vacuum cleaner perfectly fits the CDIO-framework. The case of the Dreamliner at first glance, also fits the CDIO-framework, conceive the new plane, design the new plane, implement the design by using existing disciplinary knowledge and operate the plane. Apart from the fact that the project ended up costing double the planned costs, if not quadruple, and being overdue in delivery of the first plane by 40 months, it is a wonderful example of applied new technology. The question is however, who were responsible for the development of the new knowledge underpinning the new composite technology? Of course, these were engineers, researchers and managers! Whether they worked in science or in practice, engineers focused their development efforts over a long period to bring composite technology to its readiness as we have defined above at Level 6.

This brings us to the core question in this paper: if engineers are responsible for developing new technological knowledge, where do we teach it in the engineering curricula, and must it be at the Bachelor, Master or PhD level? And how does it relate to the CDIO-framework? A paper by Crawley, Edström and Stanko (2013) discusses the Skoltech initiative in Russia. A so-called 'green field' university that is built from scratch. Skoltech's curricula are explicitly aimed at enhancing technological entrepreneurship and innovation. Integrating CDIO-based education, cutting edge research and application forms the base for Skoltech's innovative challenge. It is Skoltech's mission to "… bridge the gap between fundamental science and innovation, to become transformative members of society …" (Skoltech website), hence we should be able to teach the process of technological innovation to our engineering students. In line with the initiative in that paper, we will discuss technological innovation at a more theoretical level that aims to connect CDIO with recent developments in the field of innovation sciences.

Most engineering programs predominantly teach existing validated engineering knowledge. And yet, the design-build projects that are part of their curricula, focus on the application of existing engineering knowledge, not on the development of new technologies, that is, technological innovation. Of course, students must learn first to develop from well-established knowledge; and then at the graduate level, the focus could be applied more on technological innovation, like the initiative of Skoltech.

Over the past decades, there has been an unprecedented growth of new technologies that reached application thresholds and were subsequently spread of the world on the wave of globalization. But, major societal challenges on energy transition, food development and sustainable growth and development require rapid, trustworthy and robust development of new technologies. Future engineers simply cannot afford to develop new technologies that take too much time, fail once these are introduced in practice and cause unexpected side effects on the long run. What 'corporate social responsibility' is for companies, is 'technological societal responsibility' for the engineer. Of course, the engineering codes come with the engineering education, but seen from the challenges society (and the world) is facing, these codes might not be sufficient if our engineers are not sufficiently aware of innovation processes or know how to develop new technologies fast and in rigours manners. Therefore, 'technological societal responsibility' is not limited to technology only.

We see this paper as a means to initiate a discussion on this subject in relation with the existing CDIO-framework. The paper discusses the innovation process of technology from an innovation perspective. First, we introduce a recent perspective on innovation in terms of the IDER-framework, which positions design and engineering apart from each other yet, symbiotically related. This framework serves as a lens to explain what has happened during the development and application of a new class of aircraft materials. Then we connect the CDIO-framework with the IDER-framework and discuss what both frameworks could do for future engineering education and especially for teaching technological innovation.

THE IDER-FRAMEWORK

This section describes the IDER-framework as a generic framework that could be seen as representative for a basic innovation cycle (Smulders, 2014). It refers to the verb of innovating that was defined earlier as 'changing an existing environment by the introduction of something new'. The IDER-framework is derived from the literature on product innovation, which, in line with the definition of innovating, describes a process of changing an existing market environment by the introduction of a new product. The product innovation model presented by Roozenburg & Eekels (1995) served as the base for the IDER-framework that was developed by Smulders, Dorst & Vermaas (2014). The increasing popularity of design thinking formed the motive for these authors to investigate the role of design methods and tools in contexts beyond its traditional application within product development. This led them to set the 'design' activity apart from the 'engineering' activity and discuss the respective contributions to the product innovation process and by doing this, identify their interrelations. From this core of product innovation, that is, the development of the product, they added the early and final activities to arrive at full-fledged innovation perspective in abstracted terms, the IDER-framework (Smulders et al., 2014).

The framework reads as follows. The first element 'I' of *initiating* covers the front end of product development by, for instance, market research and/or ethnographic studies. The second element D of *designing* concerns the development of concepts of the new product or service. The third element E covers the *engineering* and embodiment of the artifact and the associated development of the necessary manufacturing processes and tools. Engineering aims to validate and consolidate what comes out of the D element and to prepare that content for implementation in the totality of the R element. The fourth *realizing* element R aims at inserting 'life' in the value chain, that is, ramping up all activities associated with, e.g., purchasing, logistics, production, sales and use of the new product. The R-element is to be seen as a new or adapted socio-technical reality in which actors perform their value adding activities which includes the use of the new product. This situation marks the end of the innovation-cycle (and possibly the beginning of a new one). The four sequentially dependent sets of innovating activities all belong to the overall cycle of innovating as defined here, meaning, the combined activities are all aimed at changing an existing environment by introducing something new within that environment, hence, innovating (Smulders et al., 2014).

By default, the literature on product innovation focuses on the product and its directly related elements like product strategy, marketing, manufacturing and user experiences. Looking from the perspective of the 'total product', Smulders (2014) realized that the abstracted framework provides interesting footholds for generalization. The total product includes all elements that add in one way or the other value to the operational chain. Thus, beyond the actors that are directly involved with the product, there are many other actors that need to go through some sort of development cycle to prepare their contribution to fit into the overall operational activities. Such could include parts suppliers, purchasing actors, distribution and sales people, maintenance people, users, etc.

Just to illustrate, think of the department of legal affairs that details the contract with a new supplier, which is very similar to what engineers do when they detail components of the product and decide upon tolerances. And like product development, also contract development first goes to a similar cycle of 'initiation' to look for suitable suppliers, 'design' to discuss the ins and outs of what will be supplied at what time and in what quantity and quality, its guiding principle so to say. This conceptual base of the contract ends on the desks of legal department. And such changing and adapting to absorb the 'new' counts for the totality of the social-technical system that is related to the product. In other words, all knowledge necessary for enactment in the R-element becomes available from the knowledge creation activities of all the former activities, meaning all affected objects will have their own IDER-cycle. Retracing upstream in the IDER-cycle, each affected object forms an innovation activity on its own, in coherence with its direct (and indirect …) environment. If the E-element delivers the robust knowledge for its realization within the R-element, then the D-element delivers the solution for its guiding principle, the principle for or architecture of the solution which in its turn is the conceptual predecessor of its whole. The I-element then is responsible for investigating the need and scoping the size of the upcoming development cycle. Cycles are initiated by some kind of surprise (Schön, 1984), doubtful situation (Dewey, 1938), anomaly, serendipitous insights, undetermined situations, troubling observation or strategic wish. The reasoning portrait here points to the universality of the separate IDER-activities that subsequently spread all over the full length of the project as Figure 2 aims to illustrate. This observation makes the activities covered by the IDER-framework heterogeneous and applicable at any level and to any socio-technical object. It is suggested to be a 'process-within-similar process' that follows the metaphor of the nested doll, i.e. the matryoshka principle (Smulders, 2015).

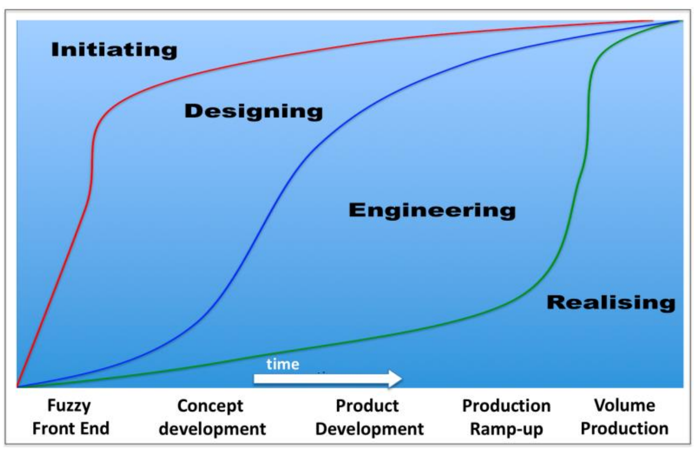

Figure 2: Schematic representation of IDER-elements over duration of innovation cycle. The vertical axis stands for total activities spend in the project, 0-100%, at each cross-section.

Over time and towards the end of the overall innovation cycle less and less objects need to go through IDER-cycles as Figure 1 illustrates. At the same time, more and more knowledge and content ends up in operational processes that progress towards their final performative state. The IDER-framework serves as a lens to analyze the technology innovation process and draw lessons towards educating our future engineers.

CASE: TECHNOLOGICAL INNOVATION

Technological innovation as we have seen in the introduction is posing interesting challenges to the innovating actors. As a reminder, we defined technology by its readiness for application which meant that the innovating actors are able to design, engineer, manufacture, operate, maintain and dispose the artefacts that use the technology. In this section, we will use the IDER-framework to discuss the development of new technologies, something we think should become part of our engineering curricula. For this purpose, we refer to a well-documented case on the development and industrial application of a new class of aircraft materials, Fibre Metal Laminates (FML) (e.g., Berends et al. 2011; Schijve 1993; Van Burg et al. 2008; Van Hengel & Kortbeek 2009; Vermeeren 2003; Vlot 2001). The data for the case study was partially collected during a three-year participation (1985-1988) of the first author in two roles: MSc-researcher Aerospace Engineering at Delft and application researcher within the confines of one of the participating companies (Alcoa). Other data came from the many publications that report on this project and irregular observations and discussions by the author with the innovating actors over the period 1989-2005.

Case narrative

The case concerns the development of an entirely new structural material for airplanes. The development of ARALL (Aramid (= Kevlar) Reinforced Aluminum Laminate) in the early 80's and GLARE (Glass Reinforced Aluminum Laminate) starting in the late 80's until its application in the fuselage of Airbus A380, beginning of this century. These two materials form the first sets belonging to new class of materials that combine the properties of aluminum with those from composites. They increase fatigue resistance of metal sheet materials. After discovery of ARALL (in the D-element of the IDER-cycle) and the early positive test results it was decided to develop the material and prepare it for the market through a certification program. The tests aimed to move into the E-element and the initial successes caused a further move towards the R-element with certification programs and production process development cycles. Positive results of the material tests with the first generation fibre material and the development of feasible production methods led to promising contacts with aircraft manufacturers. At that moment the solution principle of fibres for the new material slowly got frozen, marking the transition from D-dominated development work to E-dominated development work. The project proceeded as foreseen, until in the mid-eighties problematic issues started to surface: fibre failure and fatigue cracks under loading conditions of a fuselage, one of the most promising application areas. It was an indication that either test methods were not adequate, or the fibre metal laminate material concept itself. It proved to be both! Figure 2 illustrates the changeover of activities initiated by the surprise of fibre failure.

The 'surprise' initiated a series of research projects that had to uncover the mechanism of fibre failure. Each of these projects was a small IDER-cycle on its own, where the R of the preceding research formed the I of the next research (Smulders 2014). Ultimately and by the extensive use of microscopic investigations the complex fibre failure mechanism was uncovered (Smulders, 1988). It led to yet another doubtful situation regarding the composition of the fibre material and its application in aircraft fuselages. In parallel a first industrial application of the fibre metal laminate for the cargo door of a military air lifter looked promising at first. But after the first series of doors it was realized that from economic perspective applying ARALL was not the right solution at all. The manufacturing of the panels turned out to be far too labour intensive and costly to make up for its advantages in weight, inspection and maintenance savings. The design and engineering of the production system for these doors had been based on metal philosophy Clearly there had been not enough E-Knowledge available at that time to 'engineer', including production and assembly - this new class of materials in an optimal sense.

The above doubtful situations resulted in new IDER cycles. The new insights initiated development processes that challenged some fundamental assumptions regarding the principle of the fibre material, its D-solution so to say. At the outset, it was assumed that applying the lightest suitable fibres would be most advantageous, but microscopic research after the failures revealed that it had not been a good choice at all (Smulders 1988). This observation gave the material designers requirements to look for different class of (glass) fibres that seemed to better fulfill the requirements, although these were somewhat heavier than aramid. There was an iteration back to the D-element by opening up the seemingly frozen fibre concept and redo all the D, E and R activities that had already been done for ARALL. The result was GLARE, the second generation of fibre metal laminates. The deeper theoretical understanding of the fibre metal laminate culminated in a much more focused GLARE Technology Development program incorporating a different attitude and approach (Gunnink et al., 2003). It included adaptations of design and, manufacturing methods and a review of maintenance approaches: It was for instance discovered that conventional maintenance and repair methods that were based on metal (D-element) proved to be adequate. This prevented aircraft operators to spend scarce resources on the development and validation of entirely new maintenance methods.

The application of GLARE as dominant structural material for the skin of the fuselage of the mega plane of Airbus, the A380, shows that this time the innovating actors were better equipped to prevent costly iterations as had happened around ARALL.

The above scenario also shows that the social structure of innovating actors is far more complex than just the actors within one organization. The knowledge developed in interrelated IDER-cycles by many different actors across many different organizations resulted in a new socio-technical system of integrated knowledge elements that provided a robust base for initiating, designing, engineering and realizing new FML applications (Van Burg et al. 2008), hence, a new technology as defined above was born.

Case analysis: Technology Development

The development of the new fibre-technology, as represented in Figure 3, experienced an unexpected iteration regarding its core principle: the fibre chosen. From the perspective of the IDER-framework, one could say that an additional technological research cycle was needed to develop the new E-knowledge specifically for this new class.

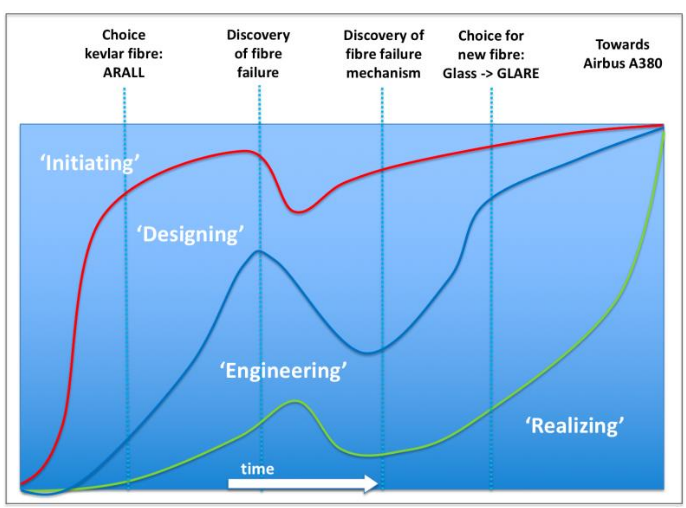

Figure 3: Schematic representation of the iterative trajectory developing FML-technology

What exactly constitutes E-knowledge and how does this come about? One could describe the notion of E-knowledge as follows: E-knowledge allows the user to design and engineer new products within the confines of a given and validated body of knowledge covering the field of that particular class of products. This is what most engineering curricula teach: how to design and engineer products related to a certain disciplinary class of products (bridges, dikes, ships, planes, etc.). Let's have a quick look at what scientific research within the engineering sciences actually aims to achieve. Scientific researchers, as discussed by De Groot (1994), Dorst (2008) and others, embark on activities that, roughly, follow the sequence: observe, describe, understand, explain, predict and prescribe, hence validated engineering knowledge. Figure 4 provides a schematic overview of this sequence from left to right (Smulders & De Bont, 2013).

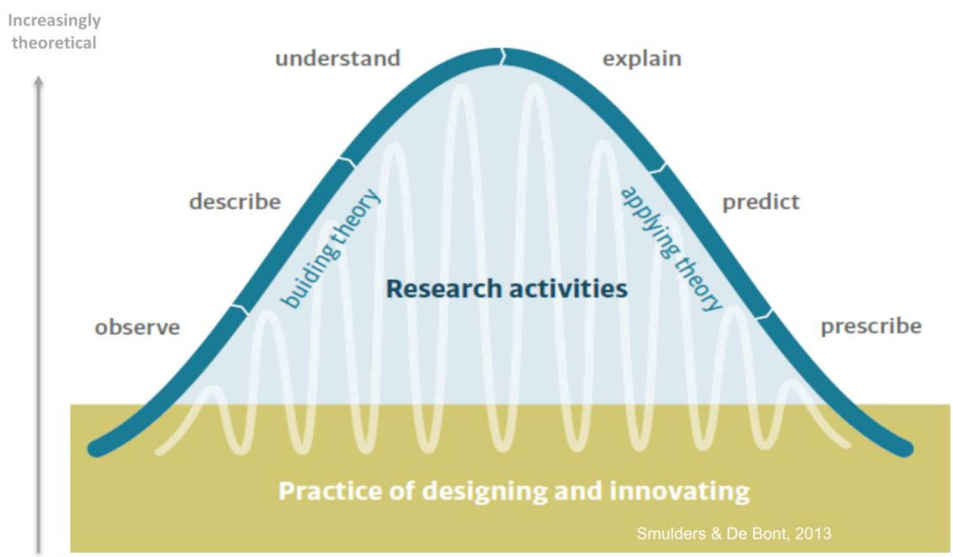

Figure 4: Schematic representation of the empirical trajectory of science (Smulders & De Bont, 2013)

The research activities aim to form theoretical explanations of real world phenomena and, based on these, developing methods and tools that are of value to those applying them in society, business, or engineering. For instance, scientific research in a lot of the engineering fields has resulted in handbooks with methods for dike design, aircraft design, bridge design, et cetera that prescribe (right side) the way these objects should be designed and engineered. These handbooks provide prescriptions like, 'if you are in situation x then do y for resolution'. In Figure 4, the research activities on the left side of the curve have a fundamental orientation, whereas the research activities on the right have an applied orientation. In general, on the left side the aim is to build theories and on the right side to test and apply them. Depending on goals and situational factors, researchers choose a suitable research approach from a large array of research methods. For instance, the situation of fibre failure was not 'predicted' as such and could not be 'explained' by the existing theories in the field. Such required a more fundamental and 'grounded approach' that followed the trajectory of observing, describing, understanding towards explaining the phenomenon of fibre failure. Once this was explicit, predictive experiments could be performed to prove the mechanism (Smulders, 1988). The changeover from aramid to glass fibres then pushed the research activities - for the second time – to the right side of the curve. The trajectory of technology development. Like that for the fibre metal laminate materials, typically aims to arrive at the right side of the curve where the new E-knowledge has been transformed into predictive and prescriptive forms.

The relation between the IDER-framework and the research perspective is explained as follows. The I-element typically is closely related to the curiosity of the researcher or to similar things as described above, surprises, anomalies, etc. In the case of technology development, it is the need for developing new robust E-knowledge. The D-element then covers the choice for the right research approach and depends on the research question. The E-element is formed by the application of the existing research methodology in order to arrive at falsifiable research results. The resulting conclusions are to be seen as new knowledge that belong to the R-element and possibly bear thoughts that initiate a subsequent research cycle. In recap, over the course of the full trajectory of the new fibre-metal technology development, many smaller and larger IDER-cycles delivered new knowledge, insights and formulas, that in total resulted in the new technology, validated to the standards in aviation and therefore crossed the threshold of applicability in the Airbus A380. All the individual research and development projects are to be seen as innovation cycles that each follow the IDER-sequence and contribute to the overall innovation cycle. This brings us to the final section in which we compare CDIO framework with the IDER-framework to arrive at some thoughts for the future of engineering education that could include technological innovation.

HOW TO EDUCATE FOR TECHNOLOGICAL INNOVATION: IDER & CDIO?

How do the CDIO and IDER frameworks contribute to engineering education for the case of teaching the fundamentals of technological innovation? Let's first reflect on what we have seen so far. Initially we defined technological innovation by its readiness for application in business. Based on what we have seen in this paper we could go one step further and define the verb not just its end result: innovating for new technologies. From this perspective, single-loop innovating concerns the realization of new (class of) products with the use of an existing body of E-knowledge. The development of new technologies for a new class of products is then to be regarded as a double-loop innovating process: the first loop concerns the new class of products and the second loop concerns the new E-knowledge that is required to bring the new class of products to live (Smulders, 2014). Although Smulders sees innovating as situational, which means that discriminating between these forms of innovating must be seen from the perspective of the actual innovator, within this paper we take a more aggregated perspective at the level of the actors within the technology development process. All innovating actors in coherence with each other go through a double-loop innovating process, whereas the individuals might be involved in a single- or double-loop innovating activity. It depends on their personal situation and context.

And so, the verb of technological innovating covers the series of development activities that aim to create a new or adapted body of (E-) knowledge that allows the users to deploy such for the purpose of initiating, designing, engineering and realizing new objects within a new class of objects. The development of a new technology is a double-loop innovating process that is followed by a longer series of single-loop innovating processes that create new objects within the confines of that particular technological body of knowledge.

Apart from some semantic issues, both frameworks seem to support the single-loop innovating activities. Remains the question, how could these frameworks contribute to the development of a new body of E-knowledge? We have described the relationship between IDER-framework and the research activities that aim to develop new E-knowledge. It shouldn't be too difficult to use the CDIO-framework for the same purpose, however, that would require a similar abstracted perspective on the constituting CDIO-elements.

Let us return to the first paper on the IDER-framework by Smulders et al (2014). Since they were interested in the application of the D-element beyond its traditional domain, they also addressed the socio-interactive dimension among the elements. Issues like transfer of knowledge and insights from one group of actors to another sequentially dependent group, for instance from actors dominantly working on D-like activities to actors with an E-dominance. Scientific work on the socio-interactive dimension finds itself still on the left side of the science model (Figure 4), whereas the engineering sciences of existing technologies have reached the prescriptive state on the far-right side. Setting these thoughts apart for a minute, the interesting observation here is, that starting from the IDER-framework rooted in innovation sciences, we were able to go beyond the CDIO-framework to initiate a discussion on technological innovation. The perspective on technological innovation as introduced here shows that both frameworks seem to cover in abstracted sense a generic and cyclic process of developing new objects, either through practical development activities, through fundamental research cycles or in a Deweyan sense through both, combining deep specialized practice with deep fundamental science (e.g. Stompff, 2012). This brings us back to the question: how can we apply these insights for educational purposes?

It is not realistic to build dedicated educational programs that let engineering students experience what it is like to develop new technologies. But, at present we only teach them the scientifically validated technologies and let them, by means of the CDIO ideas, experience how to apply these in multi-disciplinary settings. What should we teach them to experience or learn about the process of technological innovation?

What we are teaching today is actually the result of a technological innovation process in the past. The existing technologies similarly will have gone through many iterative cycles of trial and error, in both domains, science and practice and with the involvement and contributions of many disciplines and stakeholders. Uncovering the history of the technological innovating activities through the lens of a suitable innovation framework (CDIO, IDER, Dewey, others) and integrated within a socio-interactive lens. Not storytelling on facts and dates, but as a technological innovation narrative using a dedicated vocabulary that spans the full width of what has happened, yet is generic enough to be applicable for all technological innovation processes. Paying explicit attention to the perspective of the involved innovating actors will bring the story to life. What troubles did they encounter? What assumptions were needed to go and how was did accepted? How did they conquer resistance to change? Basically, building a case through an innovation theoretical lens combined with a socio-interactive lens. The didactic form in which this could be taught is yet another challenge. The full range of didactics opens up here, ranging from mini projects to serious gaming, from making a movie based on the narrative to creating a new narrative on tech-innovation of not too complicated technology.

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BIOGRAPHICAL INFORMATION

Frido Smulders, PhD. is Associate Professor, Design Innovation & Entrepreneurship at the School of Industrial Design Engineering of Delft University of Technology. In addition, he is TU Delft Educational Fellow. He holds a PhD in Innovation Sciences at Delft and BSc & MSc degrees in Aerospace Engineering also from Delft. His MSc-research in the material sciences resulted in Glare, the material now applied in the fuselage of Airbus A380. His present research focuses on the phenomenon of innovation and more recently also on the related topic of entrepreneurship. He has an almost utopian aim to uncover the fundamental building blocks/molecules of what (technological) innovating really is. He has authored and co-authored 80+ articles and book chapters including some publications in the field of education. His career in business prior to rejoining academia spans from concept engineer in the Offshore Industry (SBM Offshore) to materials specialist in Aerospace Industry (Alcoa), and many years as a management consultant in the field of innovation and technology.

Aldert Kamp is the Director of Education for TU Delft Faculty of Aerospace Engineering since 2007 and Co-director of the CDIO-initiative. He is deeply involved in the rethinking of higher engineering education with a horizon of 2030. More than 20 years of industrial experience in space systems engineering, 15 years of academic teaching, educational management and leadership, and an in-depth study of trends in society, engineering and higher engineering education, have given him good insight in the competencies engineering students need at graduation for a successful career in the rapidly changing world. He is the author of the report “Engineering Education in a Rapidly Changing World – Rethinking the Vision for Higher Engineering Education” and fervent blogger about “Adapting Engineering Education to Change”.

Clement Fortin is Interim Provost and Dean of Faculty and Post-doctoral Affairs at Skoltech in Moscow. His current research interests focuses on concurrent system and product development and their integration with technology development and PLM systems. At Skoltech, he is also working on the further development of the CDIO principles to the graduate studies level.

Corresponding author

Dr. Frido Smulders
Delft University of Technology
15 Landbergstraat
Delft, 2628CE, The Netherlands
31-614-325-265
f.e.h.m.smulders@tudelft.nl

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VISUALIZING 17 YEARS OF CDIO INFLUENCE VIA BIBLIOMETRIC DATA ANALYSIS

Alexandra Meikleham, Ron Hugo

Department of Mechanical and Manufacturing Engineering, University of Calgary

Aldert Kamp

Delft University of Technology, Delft, the Netherlands

Johan Malmqvist

Department of Industrial and Materials Science, Chalmers University of Technology, Gothenburg, Sweden

ABSTRACT

Bibliometric data analysis has gained popularity in recent years as an efficient means of visualizing multi-dimensional indicators of influence in communities of practice (Youtie & Shapira, 2008). Such an approach has been used to map emerging fields of research such as synthetic biology and nanotechnology (Shapira, Kwon, & Youtie, 2017; Youtie & Shapira, 2008). Using this approach, one can track citation and social network data over time to develop a deeper understanding of the influence of the CDIO initiative on engineering education publications since its inception (i.e., the past 17 years). In this paper, bibliometric data analysis will be used to examine how publications on the CDIO Initiative have evolved. Visualizations are presented using an open-source visualization tool, VOSViewer, and used to understand geographic distribution and co-authorship. A word frequency and co-occurrence analysis has been used to analyze title and abstract data over the same time period. Geographic author network analysis reveals continued growth in regional collaborations over the past seventeen years. Co-authorship by author name reveals a core community of researchers, which has diverged over time into dispersed collaboration groups. Word co-occurrence analysis of title and abstract data from Scopus reveals that design-implement and project-based learning activities have been the central topic of CDIO-related engineering education literature over this time period. An analysis of the terms “faculty competence” and “learning assessment” indicates that these topics are comparatively under-served in the literature, representing fertile research topics for practitioners. The benefit of this research is to provide insight to past development areas and opportunities for growth in the CDIO Initiative.

INTRODUCTION

Since 2000, the CDIO Initiative has grown from a collaboration between four institutions in two countries into a world-wide organization comprised of over 130 institutions. As the initiative continues to mature and expand it can be healthy to reflect on the evolution of the organization by conducting a historical review from a variety of perspectives. This can provide an understanding of past impact and identify new areas for future direction and influence. While the CDIO online library presents a rich source of bibliometric data waiting to be mined, this body of knowledge could also be considered to reflect more internally-focused dialogue. In reflecting on future directions for the initiative, another valuable perspective could be to better understand how the initiative has influenced publishing and external communities of practice. Both approaches provide different forms of valuable information that, when taken together, can better support decision-making. For this analysis, we have probed how literature that discusses engineering education and CDIO appearing in the world's largest database of peer-reviewed literature, Scopus (and for some analyses Web of Science), has evolved since 2002.

VOSViewer

VOSViewer is open-source software that uses a mapping technique called visualization of similarities. It aims to locate items in a dataset using a 2-dimensional visual, with distances between items reflecting their relatedness. The *distance* between any two items reflects the similarity of the items as accurately as possible, and the smaller the distance between two items the stronger the relation. This is achieved by minimizing the weighted sum of the squared distances between all pairs (van Eck & Waltman, 2011). The size of circles in a visual indicates the total number of co-occurrences, with larger circles indicating more occurrences. Colours are also used to indicate clusters (or communities), which are terms or items that are related to one another.

METHODOLOGY

Data Set

Scopus and Web of Science were used to conduct our literature search; these databases do not include proceedings available from the online library on CDIO.org, and therefore represent a mutually exclusive dataset. Scopus by Elsevier, is the world's largest database of peer-reviewed literature. It provides access to scientific journals, books and conference proceedings in a diverse set of fields. Web of Science is another database which covers publications from as early as 1900 and contains over 90 million records. These two databases were chosen to create the data set for this analysis as they best represent a broader set of publication sources external to the CDIO initiative. Both websites are designed to provide easy export of .csv files for use in bibliometric and altmetric analyses – including title, author, and abstract fields. The VOSViewer software was also built to import and easily analyze Web of Science and Scopus corpus files, making the analysis more repeatable and consistent.

Search Terms

A combination of "engineering education" and "CDIO" were used as search terms for this analysis. Searching "engineering education" in Scopus returned over 700,000 results. Adding CDIO as an additional search term in all fields limited the results to 1,355 hits. In Web of Science a search on "engineering education" in topic returned 25,000+ results; adding CDIO as a co-search term in ALL fields returned 216 items. A database was then created combining the results from Scopus and Web of Science, and after removing duplicates, 1,453 unique entries were found from the period 2002-2018. The search criteria do not imply that relevant records resulted from only CDIO researchers or CDIO community members. The choice of search criteria was to reveal influence by the CDIO initiative in that the publications contain mentions to both engineering education and CDIO, which can provide some indication to broader publication trends which reference to both themes.

VOSViewer Analysis

The program is currently built to handle files from a number of popular databases, such as Web of Science and Scopus, however each database formats their citation data in a slightly different manner. It is possible to combine data from multiple databases into the corpus of one standard accepted format, however the citation data must all be homogenous for the program to work properly. For example, if Scopus formats author names as Doe, J.A. and another database formats its authors as JA Doe these will be treated as separate entities. This renders the process of analyzing data from multiple different sources simultaneously a prohibitive process for large datasets.

In deciding which database to use in this analysis it was therefore necessary to take an either-or approach between using external databases or using the CDIO.org database, as citation data is formatted differently in each. It was decided that the focus of this paper would be on trends in CDIO publishing in external databases such as Scopus and Web of Science as these are directly compatible with VoSViewer; CDIO.org library data has therefore been left for future analysis.

The analysis was broken up into several time steps, and cumulative data was used at each time step. For example, 2002-2010 analysis includes the same data from 2002-2007, with 2008-2010 added in. The justification for this was that we were interested in visualizing how the CDIO initiative has potentially influenced external network development over time. As networks are human relationships and do not dissolve after the year a paper is authored, we found it more interesting to visualize over time how the network changed as new relationships were added (rather than only looking at new relationships formed in the time span). Clusters, or colours, are considered to be communities of similarly grouped items (van Eck & Waltman, 2011).

Two types of analyses were conducted:

- Analysis 1 - Co-authorship links based on country of affiliation for over 41 countries. This analysis was to visualize how networks of authors across diverse geographies have collaborated on publications associated with engineering education and CDIO, and how these networks have evolved over time.
- Analysis 2 - Co-authorship links based on author linkages for over 3000 authors with co-authorship. This analysis shows which authors wrote papers together. The full counting method was used, where each co-author was counted as a full author for the paper. Another visualization technique is available using fractional or normalized counting, which is utilized to provide a more consistent basis on which to compare different fields of study (Waltman & van Eck, 2013). Since we were less concerned about scaled impact, and more about community trends within only one field, full counting was used. Only Scopus results were used for this particular analysis as the formatting between the two databases was not consistent and Scopus provided a richer dataset than Web of Science.

Word Frequency Analysis

Word frequency and co-occurrence analysis based on title and abstract data from Scopus (1293 unique entries) was completed to track trends in idea clusters (themes) in that database over time. A corpus of title and abstract data was created for the year divisions: 2002-2007; 2002-2010; 2002-2012; 2002-2014; 2002-2016; 2002-2018 (cumulative data) as well as 2002-2007; 2008-2010; 2011-2012; 2013-2014; 2015-2018 (non-cumulative data). Both cumulative and non-cumulative date ranges were analyzed to get a better sense of which themes persisted across time periods and also to gain deeper insight into whether there were trends that were more ephemeral. Stop-words such as: the, and, an, and is, were removed, comprising over 40,000 stop words.

A word frequency analysis was then conducted using DCode (dcode.fr), a free online tool that can calculate frequency of phrases within a text corpus. Utilizing a tool that automatically parsed the results presented benefits and drawbacks. A benefit was that it enabled the processing of a significant number of phrases in a relatively short period of time: some year ranges contained over 30,000 multi-word phrases. A drawback was that some of the results contained errors, for example: returning a result which was not a two-word phrase. The most relevant results (greater than 10 mentions) were cleaned manually, removing any irrelevant phrases.

Rank of frequencies of two-word engineering discipline phrases mentioned in the literature was also conducted and compared to available survey data from Malmqvist, Hugo, & Kjellberg (2015).

Word frequency analysis and visualization techniques were utilized to identify the most mentioned themes in the literature, and how phrases related to the “essential” CDIO standards (Edström & Kolmos, 2014) have appeared over time. Single, two- and three-word phrase frequencies were analyzed and the most relevant findings were reported. A word cloud and treemap were generated based on total cumulative occurrences of two-word phrases, while the trends of several relevant themes associated with CDIO standards were also discussed across.

FINDINGS/DISCUSSION

A breakdown of the results by publication type can be found in Table 1. The majority of Scopus publications were peer-reviewed articles and Web of Science publications were proceedings papers. The database comprised of publications from over 450 different sources. No CDIO conference proceedings were included in the database.

Table 1. Frequency of publication type by database

Type	Scopus	Web of Science	Total
Article	344	3	347
Article in press	2		2
Book			
Book Chapter	59		59
Conference Paper	881		881
Editorial	2		2
Proceedings Paper		131	131
Review	4		4
Total	1292	134	1426

A visualization of frequency of publication types by year and database can be found in Figure 1 and Figure 2.

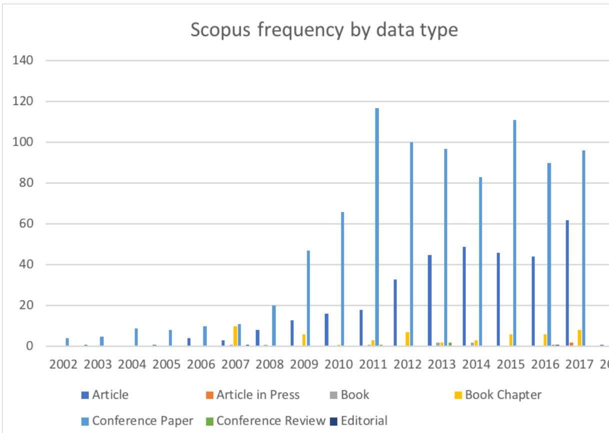


Figure 1. Frequency of publication by year, by data type, Scopus.

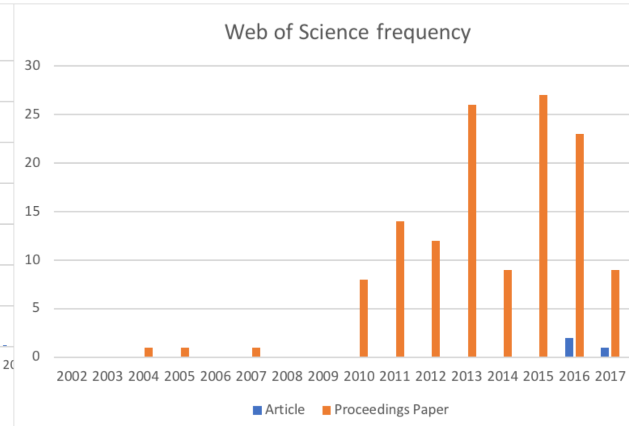


Figure 2. Frequency of publication by year, by data type, Web of Science

An aggregation of frequency of publication by year across the two databases is shown in Figure 3.

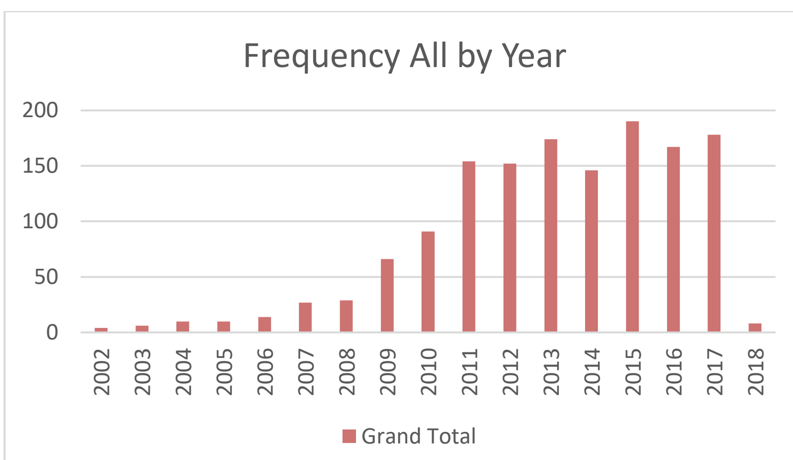


Figure 3. Frequency of total publication by year, both databases

A log-linear and log-log plot of the number of publications vs year number (from 1-17) was completed and are shown in Figure 4 and Figure 5.

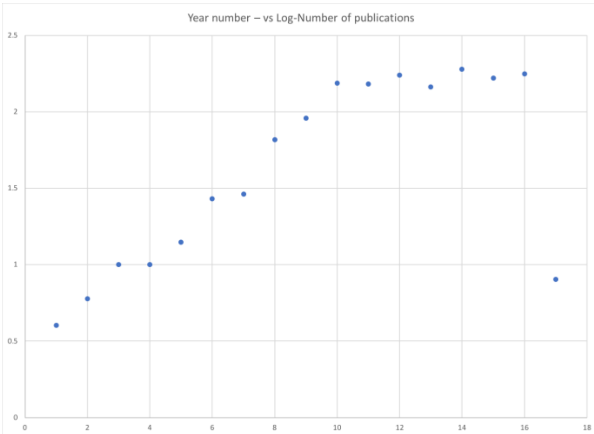


Figure 4. Year number vs. Log-Number of publications – all databases.

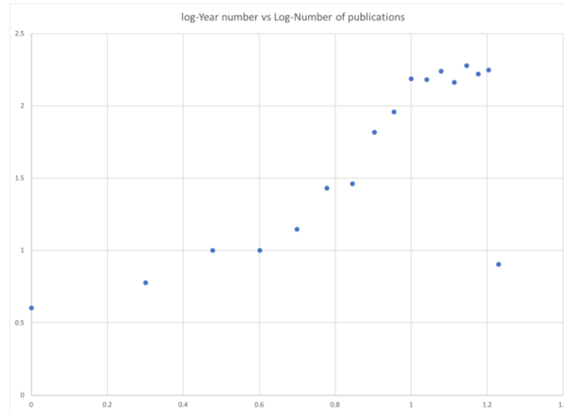
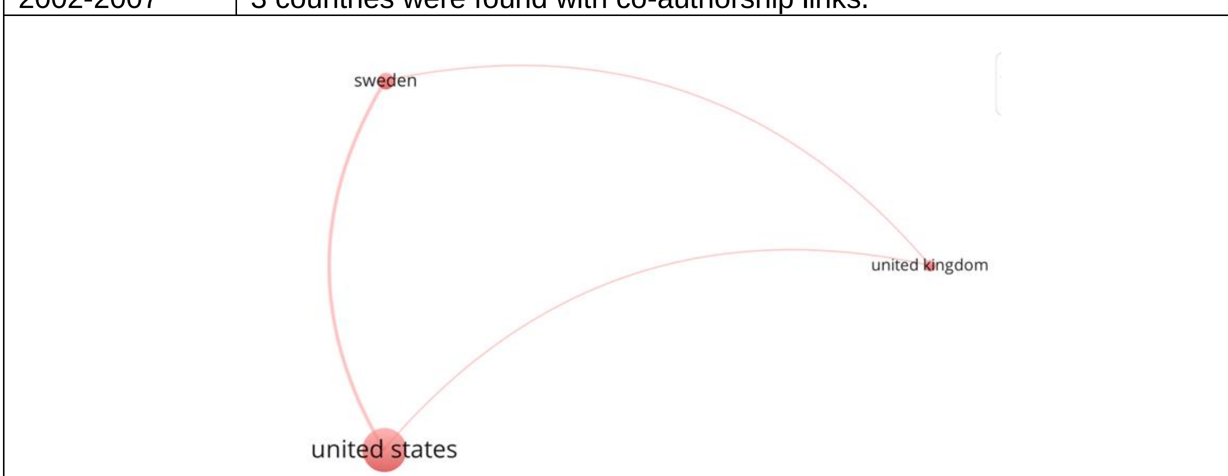


Figure 5. Log-Log- Year vs Number of publications – all databases.

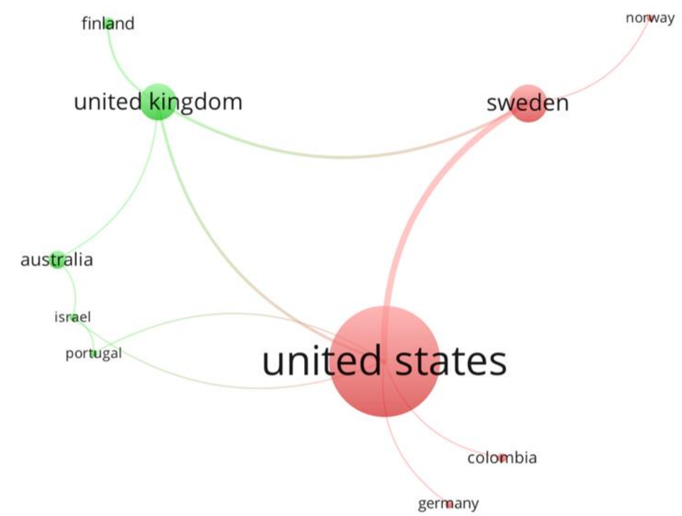
The log-log graph reveals that publication frequency underwent a power-law growth between 2000-2011, indicated by the approximately linear portion of the log-log graph. Since 2011, publication growth has reached a relatively steady state (flat region), indicating that CDIO has permeated into engineering education literature to its maximum extent in the absence of any major changes in its approach. The apparent outlier on the graph coincides with 2018 (year 17 on this graph) for which there are currently only a few publications.

Analysis 1 – Country Co-authorship Analysis

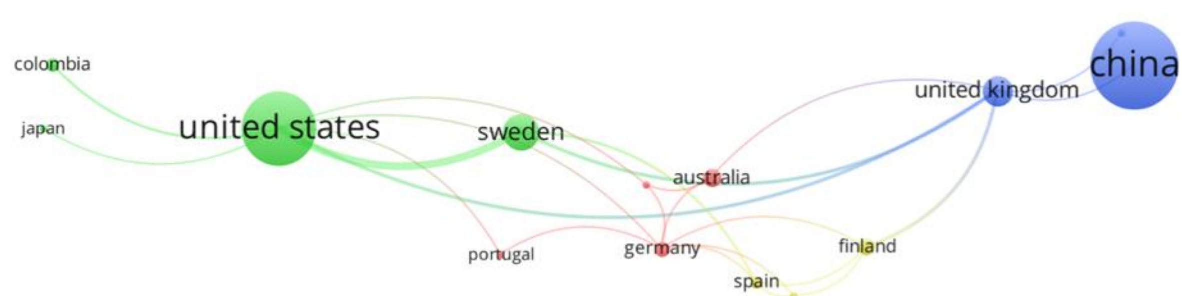
The initial analysis was performed on a year-by-year incremental basis, however, the most visually dynamic ranges were found to correspond to years that included changes in publication rate. With this, 2002 to 2007 formed the initial duration, and then this duration was extended to include years 2010, 2012, 2014, 2016, and 2018. The database file was imported into VOSViewer and co-authorship analysis by country was chosen. This analysis treats countries in the author affiliation field as co-occurring. A threshold value of a minimum of 3 documents to be published by a particular country was used for this analysis. The number of countries with connections that met this criteria for each age range are shown below.

2002-2007	3 countries were found with co-authorship links.
	

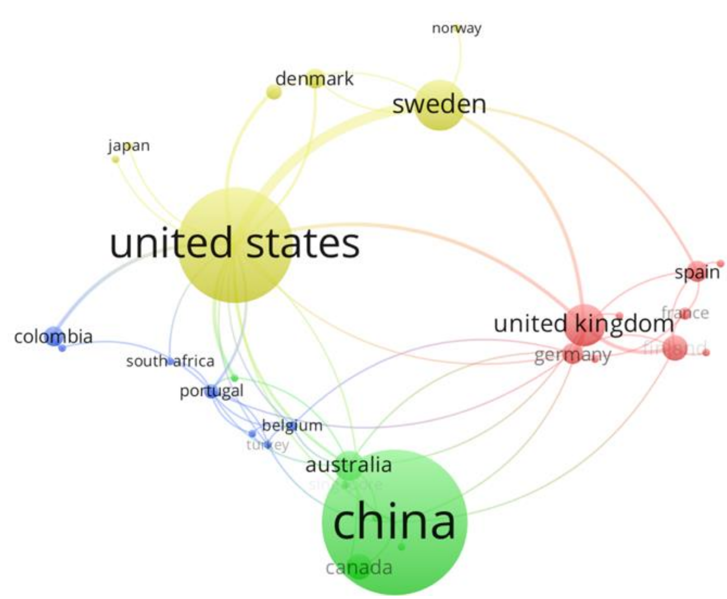
2002-2010	10 countries were found with co-authorship links, 2 clusters were formed



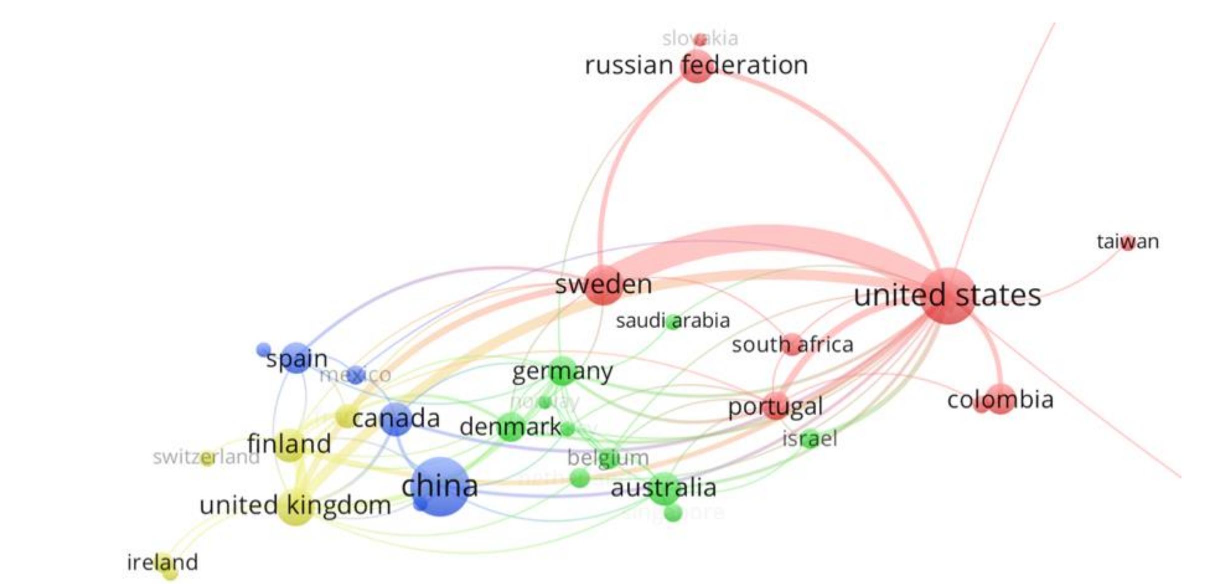
2002-2012	14 countries were found with co-authorship links, 4 clusters were formed



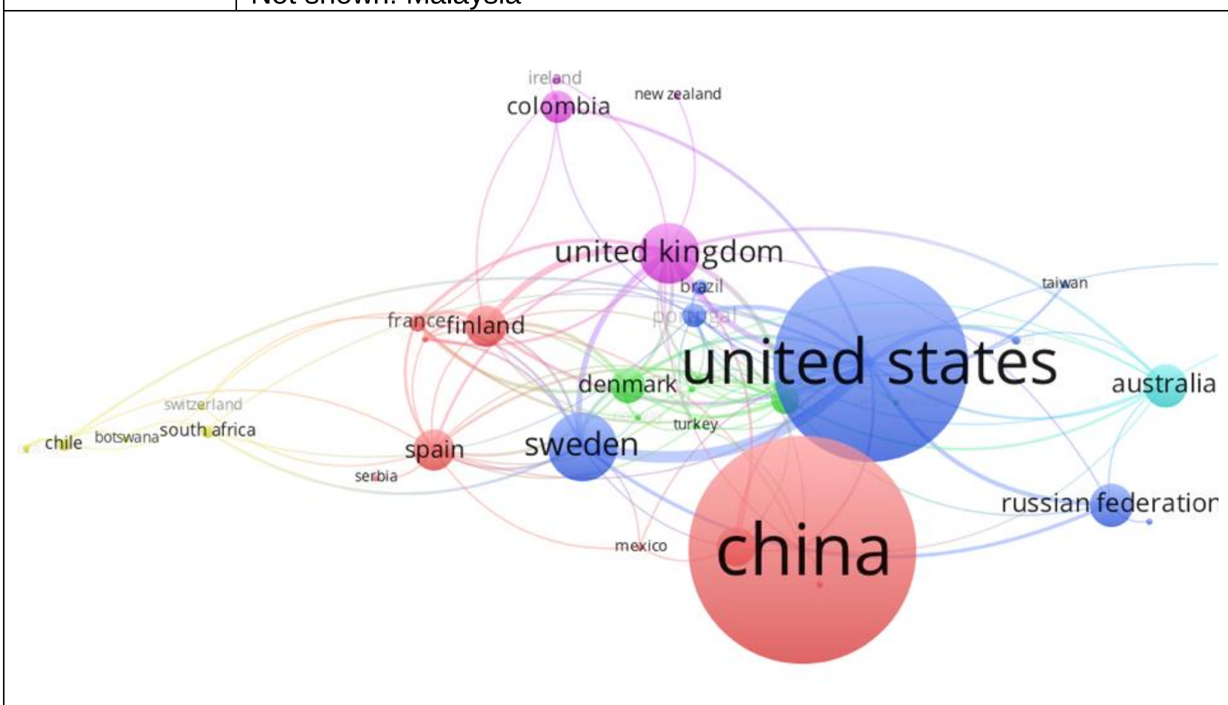
2002-2014	28 countries were found with co-authorship links, 4 clusters were formed



2002-2016	37 countries were found with co-authorship links, 4 clusters were formed Not shown: Malaysia, Japan, India Chile-Argentina



2002-2018	41 countries were found with co-authorship links, 6 clusters were formed Not shown: Malaysia

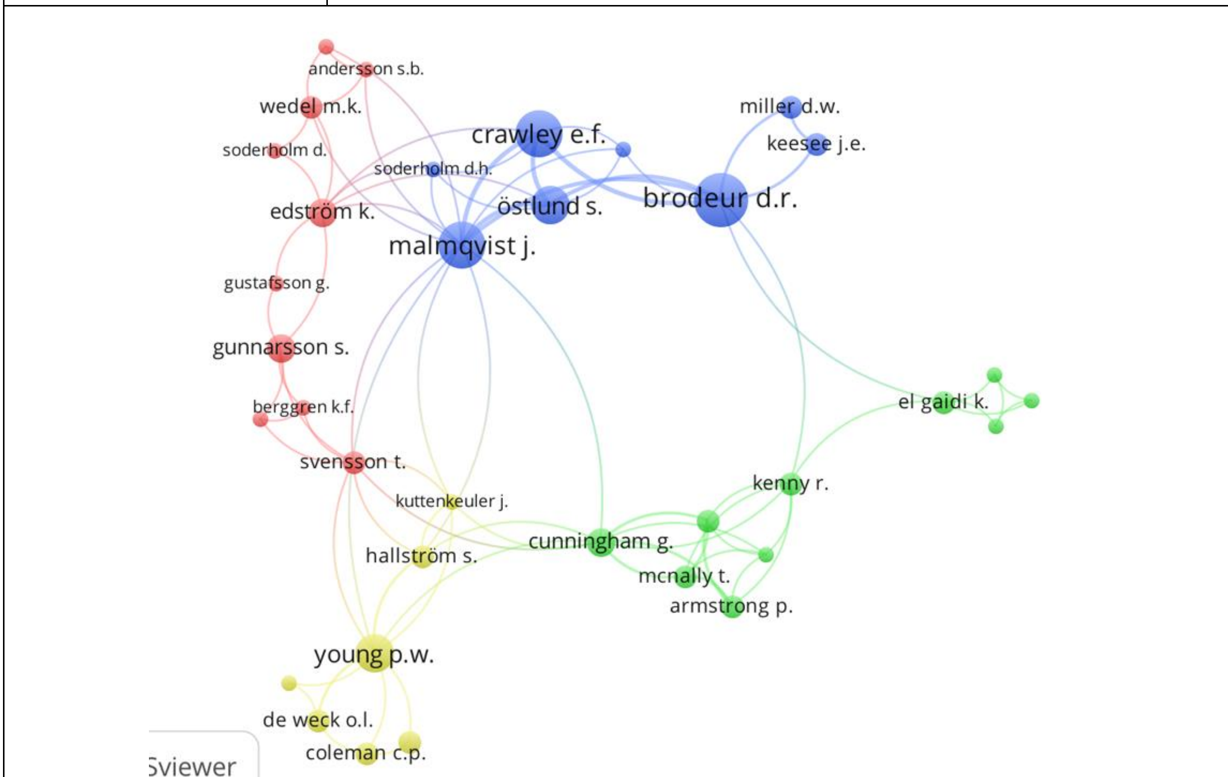


The general trend observed in this analysis is that the community of researchers publishing on engineering education and CDIO-related topics has expanded geographically over time. From 2002-2007, the geographic network as defined in this analysis consisted of three countries: Sweden, United States, and the United Kingdom. Since then an additional 38 countries have engaged in collaborations in this area. In 2012 China emerged as a significant contributor in this ecosystem. The relatively flat graphic for 2002-2012 implies that China was less integrated with the other major contributors in this region. In 2014 China became much more integrated into the community with links to many more countries. The 2002-2018 visual demonstrates a community consisting of China, Spain, Finland, France, Mexico and Serbia, and another community consisting of United States, Russian Federation, Sweden, Brazil, Portugal and others. These findings support those of a recent report by Graham (2018) in which a global shift of engineering education leadership has been observed from west to Asia and South America. The 2017 14th CDIO Conference welcomed 35 countries, which is approximately equivalent to the number of countries currently represented in this database. There is an opportunity for future research to compare whether there are any differences between these networks and the CDIO library data, and how this subset of literature differs from the broader community established in engineering educational literature in general. Any differences in community trends could represent opportunities or areas for collaboration or engagement.

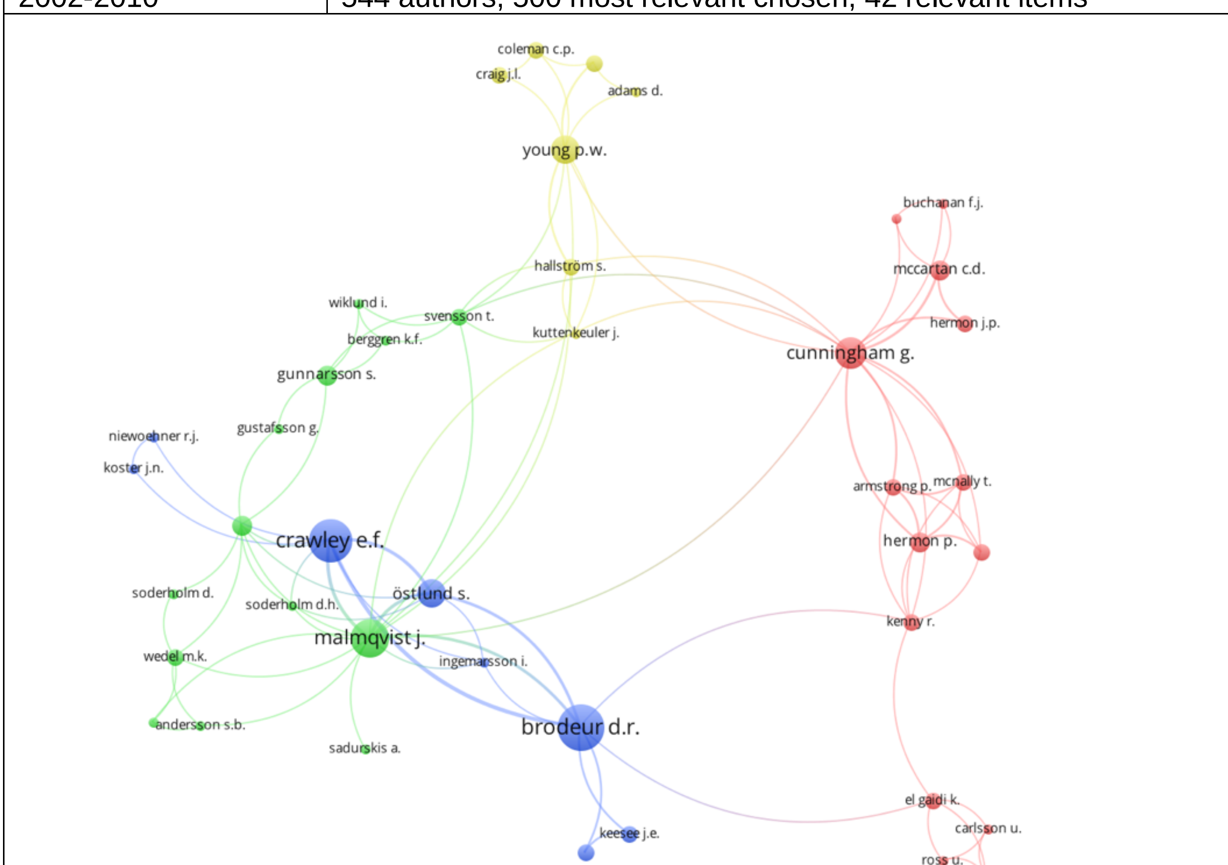
Analysis 2 - Co-Authorship analysis by author

The results from Scopus were imported into VOSViewer, and analyzed for co-authorship by name, using full-counting. Since Scopus and Web of Science export their author names in different formats, only Scopus was used as it contained more items. This visualization was challenging to create as it required significant data processing. Initial analysis yielded unexpected results as many influential authors were not visible in the output. Upon further inspection it was found that there were many authors with similar names but very different affiliations. For example, the author name Wang Y was found to be affiliated with 10 different institutions. A manual cleaning of the data was then conducted with iterations in VOSViewer until names with multiple affiliations no longer impacted the analysis. Names were coded with numbers for each new affiliation, as it was assumed that each author name with a different affiliation was a new individual. We recognize that there may have been some authors removed from the analysis who may have had more than 1 affiliation, however it was not possible to identify which combination that would have been in cases where names were affiliated with three or more institutions. We therefore opted to take a consistent approach to reduce bias in the analysis. The minimum number of documents for an author to be included in the analysis was 1 publication, however authors must have engaged in a collaboration with another author to appear in these visualizations.

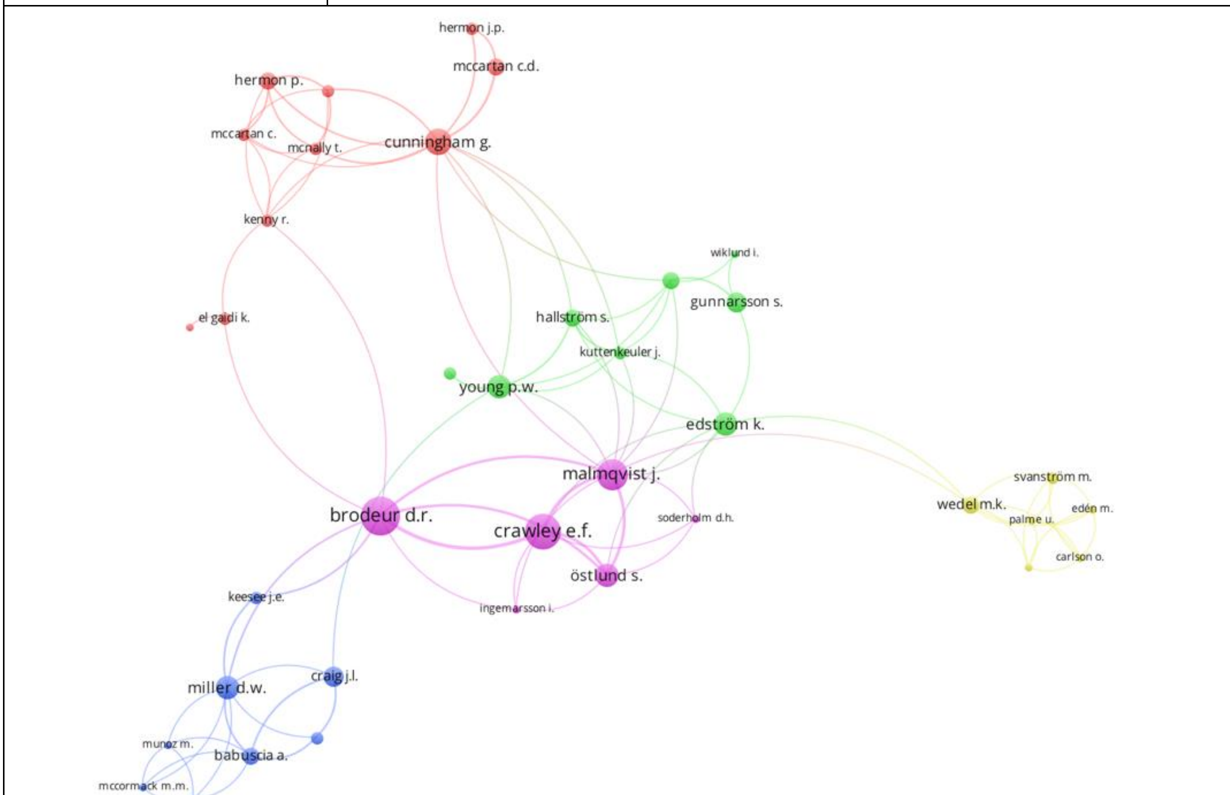
2002-2007	135 authors, 35 relevant items



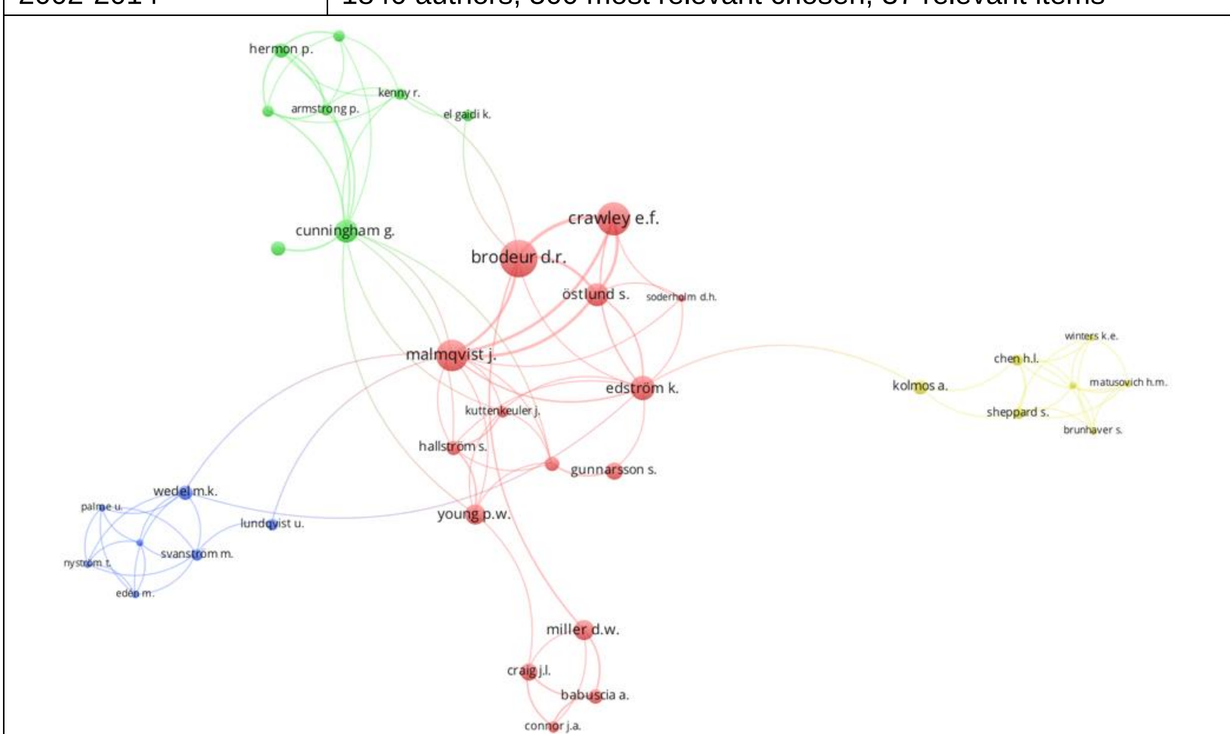
2002-2010	544 authors, 500 most relevant chosen, 42 relevant items

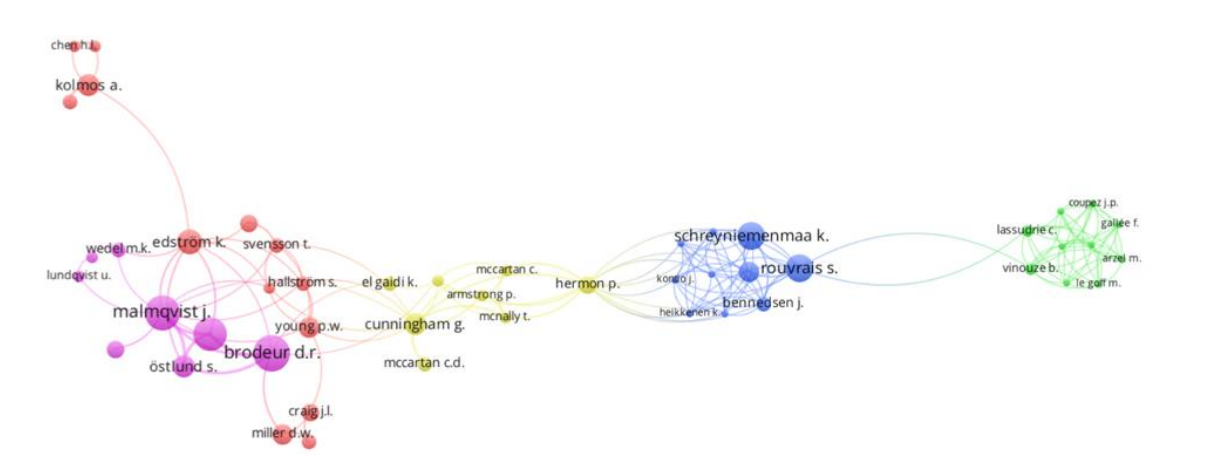
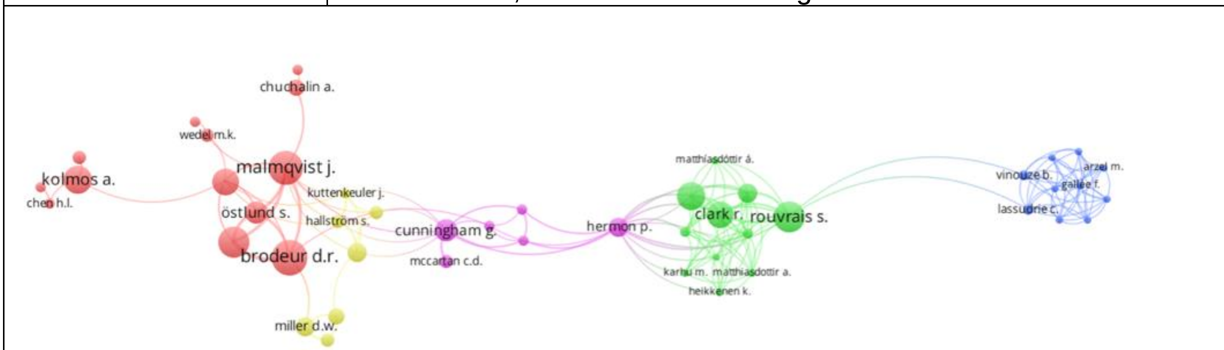


2002-2012	1181 authors, 500 most relevant chosen, 38 relevant items



2002-2014	1840 authors, 500 most relevant chosen, 37 relevant items



<table>
<tr><td>2002-2016</td><td>2584 authors, 49 relevant items</td></tr>
<tr><td colspan="2">
</td></tr>
<tr><td>2002-2018</td><td>3035 authors, 47 authors with linkages</td></tr>
<tr><td colspan="2">
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The findings from this analysis indicate that five major communities of researchers have been established over the past seventeen years. The relatively flat, dispersed visual indicates that these communities publish relatively independently from one another. Future iterations of this analysis could further probe what the demographics of each of these networks are and whether there are thematic differences in interests within each of these groups.

Analysis 3 – Word Frequency Analysis of Title and Abstract Data

An analysis of single word frequency of each of the six time periods, both cumulative and non-cumulative, revealed that the top four most frequently used words in all years were engineering, design, students, and education. This finding is not surprising and an indication that the core of the focus of the literature has not changed much over the last sixteen years, and that students, education, and design remain important themes. These findings become more revealing when two- and three-word phrases are also analyzed.

A rank-order and a log-log plot of the approximately 300 top-ranking two-word phrases is shown in Figure 6. Word frequency for 2-word phrases between 2002-2018 revealed that by far the most mentioned phrase was “engineering education”, and the second most mentioned phrase was “based-learning”.

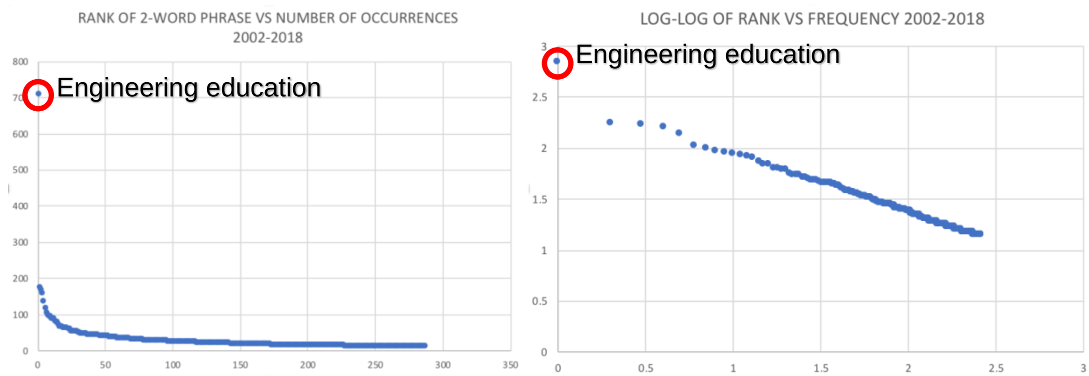

Figure 6. Rank order and log-log rank vs frequency plot of two-word phrases from 2002-2018.

The rank vs frequency (non-log) plot appears to follow Zipf's law (Zipf, 1949), which states that any text corpus will approximately follow a power law. This is further confirmed by taking the log-log of the data, which shows a roughly linear trend which is to be expected for a power-law relationship.

To create a word cloud, the term "engineering education" had to be removed. It represented 8% of all words in the corpus and could not be drawn since its weight was comparatively too high to the other words. Visualizing the log-value did not provide enough resolution between the frequencies and the word cloud lost dimensionality. A word cloud of the remaining top two-word phrases was then created and is shown in Figure 7.

Figure 7. Word cloud of 2-word phrases from titles and abstracts 2002-2018.

The word cloud is a useful tool to quickly gain insight into important phrases in the corpus. The reader can easily see that “Project Based”, “Design”, “Learning Outcomes”, and “Engineering Students” are the most popular terms. Each reader may notice different relationships and trends based on their own personal experience and biases on what they may find to be important. It is important to note that the word cloud was presented not to stand alone and be interpreted individually but rather as one data point across the entire analysis to be used to promote discussion. In the future, it could be presented next to others from the CDIO.org library or compared to the broader corpus of engineering education literature. In this paper it will be utilized in tandem with a more detailed frequency analysis of themes.

To get a better understanding of whether publishing trends on particular engineering disciplines followed the same trends as practice, rank of frequencies of two-word engineering discipline phrases in the corpus was conducted. The ranking of mention of engineering disciplines in the literature was then compared to findings from available survey data of CDIO practitioners presented in Malmqvist, Hugo, & Kjellberg (2015). The 2015 survey asked CDIO practitioners which disciplines they practiced CDIO in, and a ranking of the disciplines applying CDIO were presented. Our findings from the word frequency analysis found that mechanical engineering ranked first in number of mentions, followed by electrical engineering, then aerospace, computer science, civil engineering, chemical engineering and industrial engineering respectively. These rankings roughly accorded with rankings from the 2015 practice survey (Malmqvist et al., 2015). There were two exceptions - aerospace engineering, which represented a disproportionately high frequency of mentions, and industrial engineering which represented a disproportionately low number of mentions in comparison to the survey data. The remainder of the disciplines followed the same rank-order, indicating literature themes roughly follow the trends observed from practice (or at the very least it indicated that those publishing on their practice parallel the sample who responded to the 2015 survey). Future analysis could investigate why there are comparatively so few papers published on applications of CDIO to industrial engineering, and may represent an intervention area for the CDIO community if there are barriers that prevent publishing in this area, for example. Additionally, biomedical engineering and biological engineering were present and this discipline ranked last behind the previously mentioned disciplines, however frequency of mention have reduced to approximately 40% of the 2002-2007 value, indicating less focus in the literature over time. Emerging disciplines, such as nanotechnology engineering and robotics engineering were barely present in the literature, perhaps reflecting barriers to publishing or practicing CDIO in these areas, however this requires further investigation. A more comprehensive analysis for relevant word combinations in these areas should be conducted in the future, as emerging fields their themes and vocabulary are less homogeneous and it may be more difficult to quantify their presence by a word frequency analysis than more mature disciplines.

The remainder of the analysis focused on better understanding which CDIO standards were being represented in this corpus of literature. For this analysis the “essential” (Edström & Kolmos, 2014) CDIO standards were examined: *context, learning outcomes, integrated curriculum, design-implement experiences, integrated learning experiences, enhancement of faculty competence* (also: *faculty training, faculty development, tutor training*), *learning assessment*. In the corpus, design-implement was merged with design-implementation as these phrases both had similar number of mentions. While “context” is on the list of “essential” CDIO standards, at this level of analysis it was difficult to tell whether its use was related directly with reference to CDIO standards, or whether it was used in a sentence with some other meaning. The word “context” was therefore excluded, as a more detailed linguistic analysis would be required to better parse out when it has been used in a way that is relevant and was left for future work.

In 2002-2007 “design implement operate” was a top-ranked phrase, and remained a high-ranking phrase among the literature, indicating that authors find it a useful approach for their teaching and learning tasks. The standards analyzed and their frequencies across all years (total) were compiled in a treechart and visualized in Figure 8.

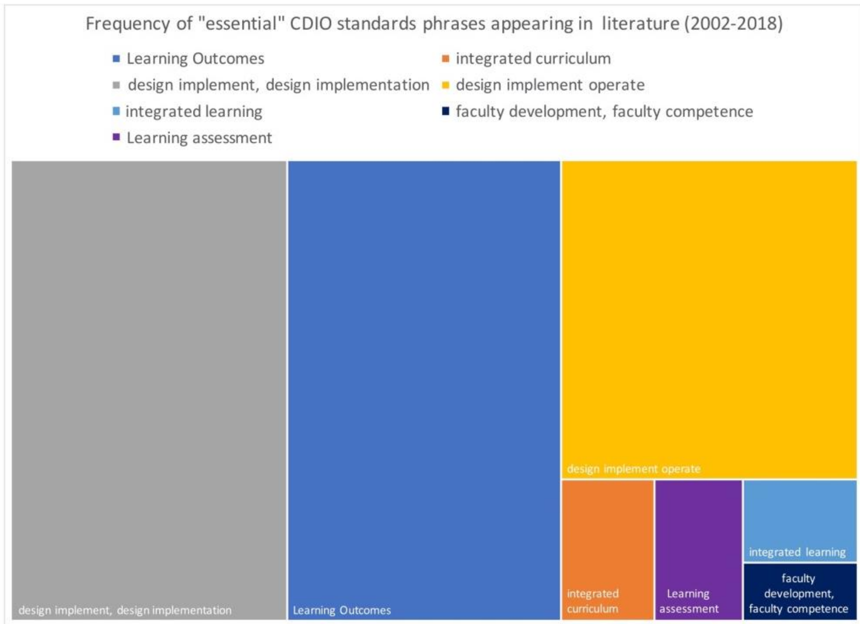

Figure 8. Frequency of essential CDIO standards phrases appearing in literature (2002-2018).

While this treemap demonstrates critical trends with respect to the CDIO standards, it doesn’t show the full picture. The theme “project based learning”, which is not a CDIO standard, went from being 21st most important from 2002-2007 to consistently ranking among the top two most mentioned phrases in the literature between 2008 and 2018 (shared with design implement). It was included in the treechart in Figure 9.

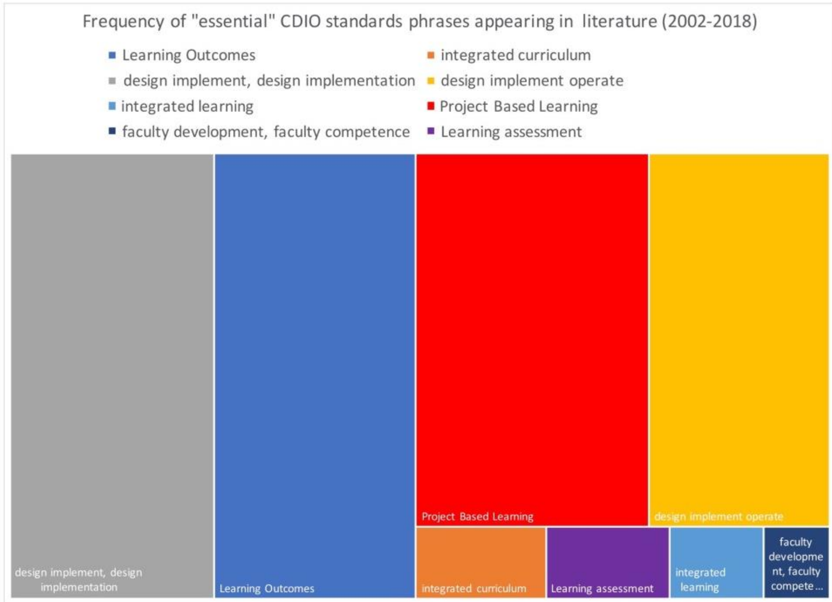

Figure 9. Treechart of total relative frequency of CDIO essential standards mentions in the literature 2002-2018, including Project Based Learning.

A more detailed picture can be drawn by examining the time-based trends associated with these themes. A stacked, normalized bar chart representing year range and relative frequency of mention of each theme is shown in Figure 10.

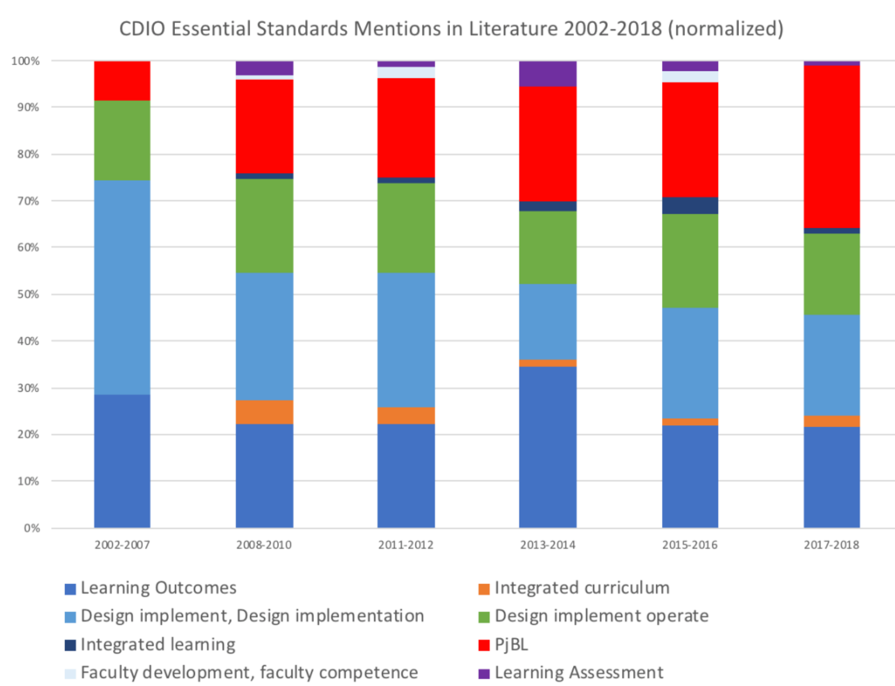

Figure 10. Relative frequencies of CDIO essential standard phrase mentions in literature by year range.

The analysis revealed that the bulk of the research in external literature is centered around techniques for teaching – papers discussed student learning and teaching practice reflecting some "essential" CDIO standards, but not all of them. "Learning outcomes" remained important across all of the years, with peak mentions in 2013-2014. The phrases "integrated curriculum" and "integrated learning" have had very few mentions in the literature over the past 17 years, with the frequency of mentions remaining relatively stable. "Design-implement", "design-implementation" and "design implement operate" have continued to be integral themes, though peak mentions occurred in 2011-2012 and have declined by about 50% since. Enhancement of faculty competence, faculty training, faculty development, tutor training have had very little reference in the literature. Learning assessment also has had very few relative mentions in the past, which is a gap given the equal emphasis one would expect it to have with learning outcomes in a constructively aligned curriculum (Anderson, Krathwohl, & Bloom, 2001). These themes (faculty competence and assessment) could represent ripe areas for future work.

A main benefit of the CDIO approach is that it provides a framework for educational reform that is holistic (Crawley et al., 2014). A key question that therefore arises from these findings is: why does the literature not appear to reflect this? A key component to CDIO is the assumption of an approach to learning that is "solution-independent" (Edström & Kolmos, 2014). These findings, however indicate that practitioners have primarily focused on application of one particular solution. Perhaps this is an indication that project-based learning is the solution that best solves the question of how to teach CDIO standards, but this debate is far from settled (Beddoes, Jesiek, & Borrego, 2010; Kirschner & Clark, 2006). If project-based learning continues to represent an increasing proportion of the literature related to CDIO, CDIO faces the risk of diluting its unique value proposition. An over-emphasis on project-based learning could lead CDIO to become synonymous with the community of practice of project-based learning; while the two have many synergies, there are critical differences (Edström & Kolmos, 2014) which should be maintained and supported.

In 2002-2007 the three-word phrase "reform engineering education" was ranked first in a tie with the phrase "design implement operate". The use of the phrase has dropped off quite remarkably, with no mentions in 2017-2018 literature whatsoever. There were zero responses for the phrases "faculty training" or "tutor training" across all years. The phrase "program evaluation" dwindled from a top rank (15) to very little importance in the literature whatsoever (rank 1679 in 2017-2018).

These findings appear to indicate that while the CDIO initiative has impacted the external literature landscape particularly in the realm of increasing publications on design-implement and project-based learning activities, discussions on systemic and institutional change have not gained the same relative momentum. PjBL and active learning design-build activities are excellent engagement mechanisms, but without sustained, deliberate, holistic stakeholder engagement, these activities may not live on in the curriculum once the instructor or faculty offering them in their course has moved on. Support for further discussion on faculty development and learning assessment is a critically important factor in the continued sustainability of the CDIO initiative, therefore a future emphasis in these areas should be maintained.

One could argue that mentions of engineering education reform have decreased, while annual publications have increased (Figure 3), particularly on innovative pedagogical practice (Figure 7-Figure 10), because reform has truly occurred. In this highly unlikely case, however, then what place does an educational reform framework play in this ecosystem as we move forward? Another interesting trend, however, is that annual publications initially followed a power-law growth, and now appear to have reached a steady-state. As CDIO matures as an organization it will be critical to better understand how it can remain relevant within an ever-evolving community of practice. It is critically important to remember that “engineering education reform” is not an end state; how we understand and implement engineering education reform is rather constantly evolving based on the expansion of knowledge and experience. As practitioners seek to embed new content, accommodate increasingly lifelong learners, and above all, incorporate the benefits of blended learning through off- and on-campus education, engineering education reform initiatives like CDIO must and will continue to adapt.

CONCLUSION

The findings in this paper are meant to support discussion and decision-making for the initiative by visualizing the evolution of CDIO influence in the field of engineering education since 2000. 1426 distinct records from Scopus and Web of Science relating to the search terms “engineering education” and “CDIO” were used for the analysis. Co-authorship analysis was completed for country and author name to visualize publication networks in this ecosystem. A word co-occurrence analysis was conducted to visualize how ideas in this realm are related to one another. The geographic network of research collaborations has expanded over time from three to 38 countries. From 2012 to 2014 China emerged as a collaborator, becoming more integrated in the network over time. Co-authorship analysis by name revealed a set of core collaborators that existed throughout the years, however these communities became more and more isolated over time. Word frequency analysis found that external literature has placed a great deal of emphasis on learning approaches and interventions, however considerably less comparative discussion has occurred on other CDIO standards such as learning assessment and faculty competence. Findings from this analysis could indicate areas that may require heavier emphasis by CDIO leaders, for example as themes around meetings or conferences, or through the support of research. Researchers and practitioners can also use these findings to guide their topics of focus for future inquiry. By supporting further dialogue in the currently under-served standards as indicated by this analysis, CDIO is more likely to maintain its distinct niche, and therefore relevance, within the engineering education ecosystem. Like so many disciplines in the 21st century, the field of engineering education reform is on the brink of major change. The shift of the centre of gravity of engineering education leadership from the western world to Asia and South America (Graham, 2018) will mean new challenges and opportunities for the CDIO initiative. The changing position of university (and its education) in society will also be an interesting consideration as CDIO continues to expand its global influence, and relevance. At the very core of the CDIO initiative’s holistic approach lies the tools and the abilities to adapt to the ever-evolving needs of the ecosystem’s many stakeholders. We expect CDIO’s commitment to continuous improvement and the community’s openness to self-reflection will allow it to adapt to the ever-changing changing world.

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BIOGRAPHICAL INFORMATION

Alexandra Meikleham is an MSc student in Mechanical engineering at the University of Calgary in Calgary, Canada. Her current research focuses on human-centered design and on engineering curriculum development.

Ron Hugo is Professor of Mechanical and Manufacturing Engineering and the Chair in Engineering Education Innovation in the Schulich School of Engineering. His research interests are in the areas of experimental fluid dynamics, energy systems, and engineering education.

Aldert Kamp is the Director of Education for TU Delft Faculty of Aerospace Engineering and Co-director of the CDIO-initiative. He is deeply involved in the rethinking of higher engineering education with a horizon of 2030. He is the author of the report "Engineering Education in a Rapidly Changing World – Rethinking the Vision for Higher Engineering Education" and fervent blogger about "Adapting Engineering Education to Change".

Johan Malmqvist is a Professor in Product Development and Dean of Education at Chalmers University of Technology, Gothenburg, Sweden. His current research focuses on information management in the product development process (PLM) and on curriculum development methodology.

Corresponding author

Alexandra Meikleham
University of Calgary
2500 University Dr. NW
Calgary, Alberta T2N1N4
1-514-567-8488
alexandra.meikleh1@ucalgary.ca

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STUDENT SUCCESS: ON THE NEED FOR A NEW STANDARD

Alejandra Gonzalez, David Barrera, Maria Patricia León, Mariela Curiel, Luis David Prieto

Facultad de Ingeniería, Pontificia Universidad Javeriana.

ABSTRACT

Engineering programs of Pontificia Universidad Javeriana have adopted the CDIO philosophy as a guideline of their curricula. The institution has made significant progress in the application of the 12 CDIO standards. However, analysis of student performance has shown weakness that are derived not only in the academic dimension, but also in other areas such as socioeconomic status and the personal features. These facts have motivated the institution to formalize a process of continuous risk monitoring and design strategies of support and accompaniment. The preliminary results show a significant impact on the students and their performance. Based on the experience of this project, a standard is proposed that guides the CDIO programs. It looks forward to articulate processes for dropout prevention and the learning assurance. This paper shows in its first section the current status of the CDIO curricula at Pontificia Javeriana University. The particular case of academic performance in first year is also analyzed. Then it is shown a dropout behavior in the school of engineering and the mechanisms for its prevention, following the STARS network guidelines. Finally, preliminary results of those strategies and the proposal of the new standard are presented.

KEYWORDS

Student Success, Drop out, Standards: 11,12.

INTRODUCTION

After three years of implementation of CDIO curriculums at Pontificia Universidad Javeriana, programs have now reached a maturity level that allows a data-driven evaluation of the process. Furthermore, from the curriculum point of view, CDIO philosophy has been adopted as context of engineering education. Learning outcomes have been also established including design experiences and introduction to engineering courses. Regarding faculty, an effort has been made to develop competences related to teaching, learning and assessment methods as well as disciplinary skills. Finally, a rigorous evaluation model, considering ABET criteria, is continuously applied. Preliminary results from this model have shown us poor performances for some of the first year students, particularly in mathematical modeling, team work and communication skills. In order to analyze the causes of these issues, focus groups and basic skill tests have been conducted. Low motivation and difficulties in the adaptation process to the university life was expressed by these students. Those behaviors cannot be identified by the evaluation program model since there is no performance indicator directly associated. An additional factor must be considered in the Colombian context: since 2015 government gives financial aids in order to improve accessibility to accredited universities. As a consequence, this public policy has increased variability in the demographic profiles for private universities. In this sense a need to characterize student population has arisen in order to establish different mechanism that could lead to the success of students.

In this paper, a new standard associated with the CDIO philosophy is proposed in order to guarantee the success of the students. Since, this success is defined as the achievement of the student engagement, it takes into account their expectations, their reality and their psychological wellbeing. Thus, a model considering transitions is proposed based on student performances. As result, a discussion of the rationality and the standard rubric is given. Finally, an application case in the Pontificia Universidad Javeriana at Bogotá, Colombia is shown.

THE CURRICULUM CONTEXT

The Faculty of Engineering of the Pontificia Universidad Javeriana, has been in a continuous curricular reflection that has been aligned with the principles of the CDIO philosophy (Crawley, E. F., 2007). The four undergraduate programs, Civil Engineering, Electronics, Industrial and Systems, have accepted these guidelines to make reforms to their programs. Those curricula are characterized by an inclination towards an education context based on the cycle of construction of products process and systems (Al-Atabi, M., 2013). They also have integrated competences and skills to the courses at an early stage, including experiences related to the first year. The pedagogical practices are diverse and respond to the training results designed for each of the courses (Crawley, E., F., 2014). On the other hand, learning assessment processes are rigorous. They feed a program evaluation model that is part of the ABET accreditation criteria. In terms of support for teaching, the University has a center for learning, teaching and evaluation (CAE + E). It looks out the development of competences in the teaching staff. It trains also professors in teaching and learning skills and its evaluation. Thus, it is evident how the engineering school is immersed in an active process of strategic planning including curricular management as a fundamental axis to ensure quality of learning. This is complemented with infrastructure. Indeed, a building of classrooms and laboratories of the School of Engineering inspired by the standard 6 CDIO is under construction.

The first year of an engineering undergraduate program at Pontificia Universidad Javeriana is designed to articulate the physics, mathematics and primary disciplinary concepts. The goal of this is to put the student in contact with their profession. Four programs have in their structure an introductory course in engineering with a project scheme focused on solving problems. Table 1 shows the structure of each engineering program.

A review of the first year courses in the four programs allows to generalize the Syllabus CDIO competences. They have been adapted to the curricula. These competences yield the learning results that are expected of the students in this stage of their formation. In general, the first year study plans seek to develop at a first level (knowing):

1. Disciplinary knowledge and reasoning (1), focused on mathematics and science (mathematics, physics chemistry) and the core and fundamental concepts of each discipline (1.2),
2. Analytical reasoning and problem solving in engineering (2.1)
3. Knowledge construction (2.2)
4. Communication skills (3.2)
5. Team group (3.1).
6. Personal skills are a strong point, since it facilitates learning and allows the development of systemic, critical and creative thinking (2.4).

Table 1. First year structure of engineering programs.

Industrial Engineering	Civil Engineering	Electronics Engineering	Systems Engineering
• Differential Calculus • Materials Science • Product Design and Engineering • Epistemology of Engineering • Int. to Physics • Int. to Industrial Engineering	• Differential Calculus • Chemistry of Materials • Graphic Expression and Geometry • Int. to Physics • Int. to Civil Engineering	• Mathematical Tools • Mathematics I • Signals Laboratory • Int. to Physics • Int. to Electronics Engineering I	• Differential Calculus • Mathematical and Computational Logic • Algorithmic Thinking • Epistemology of Engineering • Int. to Physics • Int. to Systems Engineering
• Integral Calculus • Linear Algebra • Financ. Accounting • Mechanical Physics • Principles of Economics • Human Syst and Product • Theological sense and meaning	• Integral Calculus • Linear Algebra • Mechanical Physics • Algorithmic Thinking • Topography and Photogrammetry workshop	• Mathematics II • Electric Circuits • Int. to Electronics Engineering II • Signals and Systems	• Integral Calculus • Linear Algebra • Computer Programming • Object Oriented Analysis and Design • Theological sense and meaning • Engineering Ethics

Finally, in order to motivate students to promote a context of equity and social responsibility, courses take into account the ethical vision of the engineer. This agrees with the mission of the university.

CHALLENGE OF INTEGRATINNG COMPETENCES IN THE FIRST YEAR

The teaching-learning process of the competences requires from freshmen to have a minimum level of performance in skills and knowledge. This allows them to be successful in the transition from school to undergraduate. Although the Ministry of National Education, establishes the levels of expected achievement that students should reach after high school training (Ministerio de Educación Nacional 2006), it has been shown that there is a significant gap between these expected levels and the real abilities. This reality cannot be ignored. Thus, it is responsibility of the university institutions to measure the difference and to mitigate it. In this sense, each CDIO competence integrated into the curriculum has some entry requirements that must be guaranteed. This helps to increase the achievement of the learning results of each course in the first year.

The construction of disciplinary knowledge, reasoning and the basics in mathematics and science requires the development of: numerical thinking (natural, integer, rational and real numbers), spatial thinking, geometric systems (Cartesian representation, trigonometric functions, etc), metric thinking and measurement systems (magnitudes, precision), random thinking and data systems (statistical information, information management, conditional probability), thinking of variables and algebraic and analytical systems (derived from basic functions, trigonometric functions) (Ministerio de Educación Nacional 2006).
These requirements build the body of knowledge that will allow students to learn modeling and quantitative analysis of information (Crawley, E., F., 2011). These are indispensable skills for the formulation of numerical and analytical solutions considering orders of magnitude and trends. They should be agreed with the problem identified in real context of physical and chemical phenomena. The understanding of those phenomena of the world requires primary skills of measurement and analysis of data focused on experimental inquiry. Skills of experimentation, research and discovery of knowledge require skills of analysis of information which are found primarily in the literature. Hence, clear strategies of classification and ordering of information based on reading and analysis of texts are needed. In general, the advanced development of communication skills, requires basic skills in textual production, understanding and interpretation, symbolic systems and media (Ministerio de Educación Nacional 2006).

Regarding the abilities and attitudes for each discipline, students are expected to arrive with sufficient autonomy and criteria to develop a culture of decision making, based on information and risk assessment. The aim is to motivate students to perseverance and adaption to changes. Also, they are encouraging to accept criticism and feedback of their training process and promote the balance between personal life and university life. It is considered that the students are able to recognize their weaknesses and strengths at their arrival to the university. Indeed, they create a framework for lifelong learning, in which the organization of time and resources are essential elements. Finally, a relevant process for the axis of articulation of the training processes is the motivation of the students to learn. This motivation requires recognizing of a life plan and a proactive vision to achieve it. In particular, the joint construction of this life plan is motivated at the university by forming learning communities based on teamwork. Thus, it is expected when students arrive at the university, they are able to recognize the need to establish networks, respecting diversity under a constructive and fair dialogue.

DROP OUT

An analysis of student academic performance of the School of Engineering, shows that approximately 25% of the students in the first semester enter into an academic risk situation. This occurs when they do not obtain the minimum GPA required by the program. Around 10% of students decide to suspend their studies, finishing the first year. 7% are excluded from the program in the third semester for not overcoming their risk status after 3 semesters of poor performance. Although the four undergraduate programs are in an advanced stage of implementation and the quality assurance model feeds the processes in a cycle of continuous improvement, academic risk indicators and dropout behaviors in the first semesters has become a concern. This is why they must be addressed as part of the operation. Ensuring student success, becomes a priority for the School of Engineering. Hence, a mapping of entry requirements to achieve the CDIO competencies in the first year has been determined.

Once the required competences have been identified, classification tests have been applied since 2016 to detect weaknesses in the entrance competences. This helps to design strategies that mitigate the gap between reality and the expected competencies (Lightbody, I., 2016). Four tests are applied:

- Basic skills in mathematics
- Basic language skills
- English level according to international classification
- Primary knowledge in physics

Focus groups have been developed with students and professors to gather perceptions about the CDIO curriculums, their operation, teaching practices, etc. As a last tool, the information generated by the evaluation model in the first year, gives indications of the real performance of the students. Several behaviours have been found that show weaknesses in the training in some high schools from which the students come. The mentioned results, give an idea of the type of weakness that could be explained in the diversity of students and in their different contexts (public schools, private schools, regions). Additionally, 18% of the students are beneficiaries of a National Government program seeking the best students of the country with low economic resources, to access accredited institutions of Higher Education of high quality.

This program covers the total value of the tuition and also provides support throughout the study period. The program is called "*Ser pilo paga*" and by 2017 it has reached its target of 40,000 beneficiaries. The idea is to close the inequality gaps in education in the country. Of the total beneficiaries of the program, 75% comes from official high schools and 1,784 of the total are victims of the Colombian armed conflict. This diversity in the students led us to identify not only academic, but also individual, socioeconomic and institutional risks.

Table 2. Risk classification proposed by the Ministry of National Education.

INDIVIDUAL	INSTITUTIONAL
• Age, Gender, Civil status • Family environment • Health condition and diseases • Social integration • Scheduling conflicts • Successful expectations • Pregnancy	• Academic status • University's resources • Financial support • Politic environment • Relationship between professor and student • Academic counseling • Psychological accompaniment –
ACADEMIC	**SOCIAL AND ECONOMIC**
• Academic status • School • Academic performance • Program quality • Learning and study strategies • State examination • Mathematics and Language exams • Student satisfaction level	• Socio economic level • Employment situation • Parents' employment situation • Economic dependence • Family responsibilities • Parents' educational level • Macroeconomic situation – –

The Ministry of National Education has as a work plan to increase its capacity in the development and implementation of policies and programs to promote student permanence and graduation. This must be agreed with strategies, teaching and learning methodologies, as well as in the training of the academic human team and administrative. Table 2 shows the risk classification proposed by this Ministry and some potential indicators for prevention and integral treatment that are hosted by the University. It is important to highlight that the risks are not only presented in the first year. For this reason, Pontificia Universidad Javeriana developed a model of transitions to describe the students' transit in their training.

The model has identified the essential institutional interventions to facilitate such transit. It leads to propose specific strategies to mitigate some risks, giving priority to academic risks. Figure 1 shows the student development model adapted to the engineering programs.

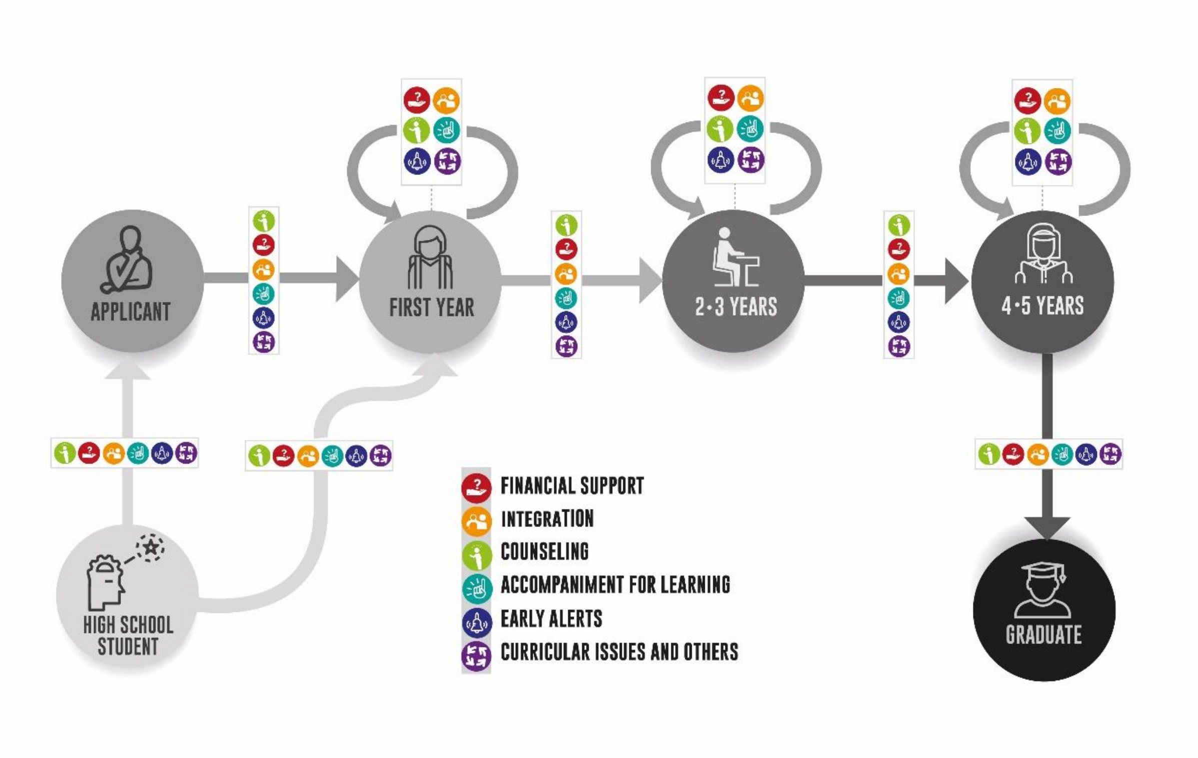

Figure 1. Student development model.

The purpose of the transitions model is to identify the accompaniment routes that will allow the student to advance in his formative process. The circles are states of a student given by their progress of their program. The arcs link these states. Those arcs are the routes that allow to pass from one state to another. The accompanying processes (circles in each arc) defining the transition routes are accumulative. Thus, each student must advance on the route and in some way complete all the conditions (processes). The proposed processes for each route coincide with the strategies, projects, policies and infrastructure that the university offers. The processes that describe the transition routes are based on the elements of Integral Formation and the accompaniment, which are elements of the Educational Project and the Mission of the University. Table 3 shows the description of each process. Four elements can be observed: a diverse student community, weaknesses in entrance competitions to the program, indicators of risks in the first year and a model of transitions that looks forward to ensure student success (McKenzie, Jo., 2017). The conjugation of these 4 elements resulted in the proposal of specific strategies for risk mitigation in the framework of an institutional program called the Student Accompaniment Program (PAE, for its acronym in Spanish).

The PAE includes four lines of work that make the transition routes of the transitions model operational:

- PAE-1: Accompaniment program for potential and enrolled students admitted to the programs.
- PAE + 1: Accompaniment program for first year students
- PAE + 2-3: Accompaniment program for students of year 2 and year 3
- PAE + 4-5: Accompaniment program for students of year 4, year 5.

Table 3. Processes in the transition routes.

Institutional process	Description
Financial support	Accompanying process related to the identification of socioeconomic and academic profiles. It can be supported through the offer of scholarships, incentives, supports and financial facilities.
Integration	Engaging the students to the educational community through continuous strategies of processes and guidelines promotion. It generates the sense of belonging to the community, induction processes and transitions.
Counselling	Support for the planning of transitions in the curriculum. It deals with the choice of strategies to overcome academic risk conditions, mobility and other degree options, among other processes.
Accompaniment for learning	Support for learning and teaching, mentors, tutors, instructors and support spaces, among other to ensures learning.
Early alerts	System for the collection, analysis of data and prediction of student behavior in all the states of the model. It allows to establish student risks including drop out. This process is constituted as an articulating axis of the other processes in the transition routes. It is structured to have coverage in different dimensions of the student training.

Similar experiences in the world allowed us to validate the model of transitions and the proposed accompaniment scheme (PAE) (Lightbody, I., 2015), (McKenzie, Jo., 2014), (McKenzie, Jo., 2016) (Wilson, T., 2017). In particular, the STARS network (REFERENCE) of the Australian university academic community reinforced these support structures. Indeed, it yields to a cooperation network between the member universities of the network and Pontificia Universidad Javeriana.

STARS is an academic network that works to provide an opportunity to know and discuss research results, good practices and innovative initiatives in order to improve the learning experiences of students in each of their transitions. STARS is subdivided into specialized networks, Table 4 shows the sub-networks and the leading university that currently supports the PAE transitions model:

Table 4. STARS sub-networks.

STARS NETWORK	***University and contact***
Mentoring, accompaniment and peer learning	Queensland University of Technology – Victoria Menzies
First year experiences	University of Technology Sydney – Kathy Egea
Experiences and resources to facilitate **STEM** training	Queensland University of Technology – Ian Lightbody
Equity for students in the context of diversity	National Centre for Student Equity in Higher Education – Nadine Zacharias
First generation at the university.	University of Wollongong – Sara Oshea

During 2017, the Faculty of Engineering has chosen to focus its efforts on the design and implementation of PAE + 1 as an integral accompaniment to first-year students in different dimensions. This is described as follows:

- Ensuring learning: it assesses and supports the improvement in knowledge, skills and aptitudes of students in the areas of mathematics, critical reading, written expression and English language proficiency. The mentioned areas are consolidated as the baseline for the development of disciplinary and skills at more advanced levels of competence.
- Integration into university life: it is the accompaniment through peers, academic advisors, professor and members of the academic community that allows the student to fully assume his role as a university student. It is a vital dimension for adaptation in each transition of the model.

- Vocational support: it is the accompaniment provided by peers, academic counselors, professors, graduates (mentors), psychologists, which allow the first-year student to understand their professional choice for engineering.
- Family environment: it is about access to information and working mechanisms to provide accompaniment in particular situations in the family environment.

Figure 2 shows the structure of PAE + 1, in which the strategies are aligned. They feed an early alert system that allows the detection of risks in an anticipated manner in the context of risk prevention actions.

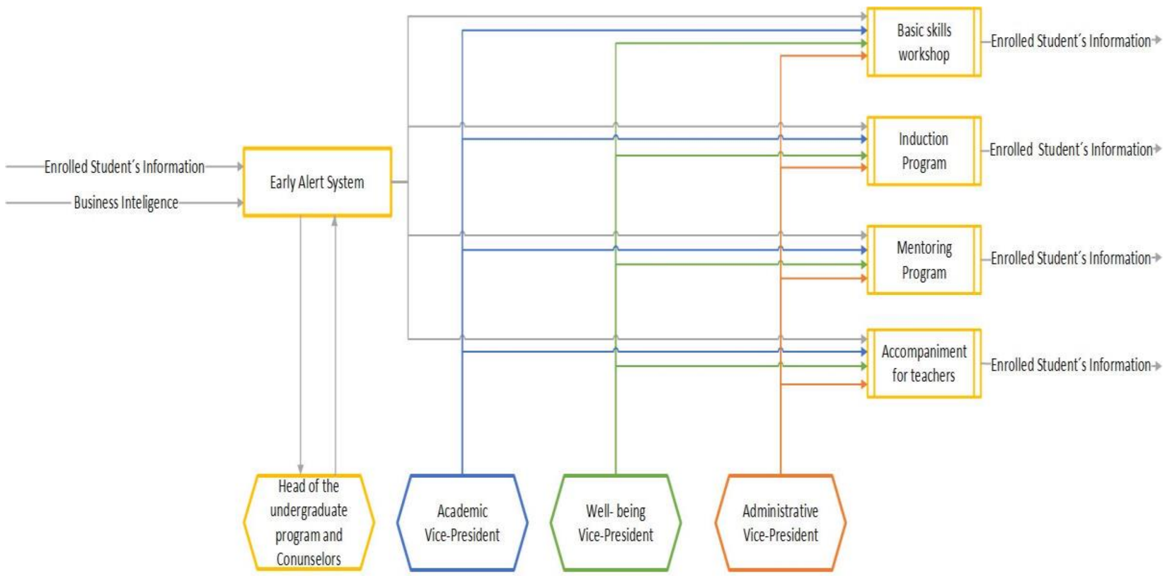

Figure 2. Structure of PAE + 1.

The early alert system

PAE + N is supported by a system for monitoring, collecting and analyzing information that supports timely decision-making in the student transitions. The system of early alerts is designed to notify the head of the program of a possible critical event related with the student permanence. This event can be at the individual, academic, socioeconomic or institutional level (Moody, H., 2015). It looks forward to reduce the vulnerability of the student population through a timely reaction. The information that feeds the scheme comes from different units and dynamics of the university. These units are the Admissions office, the academic community, the Psychological and Health Advisory Center, professors and counselors, among other actors. The primary objective of the early alert system is the creation of cause-effect models and behavior patterns of the student population.

Induction Program

Induction program seeks to impact the processes of integration into university life. It encourages the development of elements that allow students to assume their university role autonomously, responsibly and aware of the transcendence of the career within their life project. The program is oriented to a reflection about the way in which the career is integrated with this project. Additionally, the activities of the program contribute to the processes of qualitative and quantitative characterization of populations. It also motivates the appropriation of information that allows the student a harmonic adaptation to the university. Moreover, it integrates the student with the different members of the academic community.

Accompaniment of first year professors

The objective of this strategy is to offer professors, different tools to face the particularities of their courses taking into account the population. The aim is to ensure learnings and also to give vocational support. In this program, it is searched the link among critical courses within the first year in order to provide support in the design and planning phase of these courses. The idea is to give professors orientations about their teaching practices. Finally, another objective of the strategy is to generate appropriation of the transitions model. Indeed, the first semester professor become an actor for the identification of student risks.

Mentoring program

This strategy aims to facilitate an environment of trust through peer-to-peer. The accompaniment here points out to the knowledge of the institutional processes and the understanding of the educational project. It also shows the tools and supports offered by the university for overcoming academic difficulties. Mentors facilitate the identification of risk situations associated with adaptation and integration to university life or academic performance. They promote the integration of students in the educational community and also encourage the development of transversal skills. Group mentoring is chosen as a structure, in which a group of mentors is assigned to first-year students. Subgroups of mentoring are formed to create micro-communities of accompaniment. This perspective can be extended to people with more experience, graduates and entrepreneurs.

Basic skills workshop

This strategy is an extracurricular space for all first semester students. It searches to decrease academic risks. Several strategies are developed to face the demand and complexity demanded by the university. Different from a leveling course, students are classified with diagnostic tests. This classification allows the work to be focused on the particular flaws of each student. The basic skills workshop provides accompaniment to students through the reinforcement of math and communication skills. It provides tools for an effective adaptation in the college-university transition. This is an ideal space for the detection of populations at risk of dropping out. The workshop has an intensity of 3 hours per week including three components to meet the stated objectives: mathematics, communication and adaptation to university life.

RESULTS

After a year of implementation, it is possible to measure the impact of the strategies. In particular, the percentage of the population that ends the first semester in academic risk condition. According to the national definition of drop out, the impact of the strategies on this rate requires an additional year. Figure 3 shows the percentage of first semester students in academic risk condition during the last three years. The results are divided according to the starting date of the students due to the differences in the admitted population in first and second semester. As it can be seen, for students entering the first semester of the year, three of the four programs achieved a reduction in the percentage of risks during 2017. In the second semester, this reduction occurred in two of the four programs. This is due to the characteristics of the admission processes in Civil Engineering and Systems Engineering programs. For these two programs, the selection changed. As a result, during 2018, new strategies for classifying students at the time of admission are being implemented.

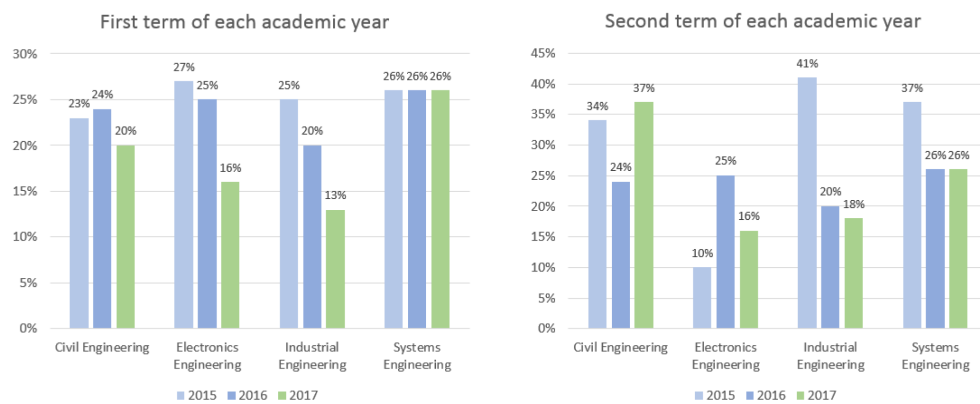

Figure 3. Percentage of first semester students in academic risk condition.

The partial results of the implementation lead to the question about the sustainability of the strategies. We argue that such sustainability is only achieved when the accompanying strategy is part of the program management. In particular, a standard associated with the maturity of this strategy must be established. In this way it will be possible to follow up the results and adjust the design of the strategies.

PROPOSED STANDARD – STUDENT SUCCESS

During the implementation of CDIO in the school of engineering of Pontificia Universidad Javeriana, we have observed benefits addressed to integrate competencies in the curricula and to the development of the same ones in the students. This philosophy together with the quality assurance system (ABET) has allowed us to find that student success not only depends on the strategies implemented in terms of curriculum. There must be a general view of the students in terms of their particular needs. Understanding the students ' context and monitoring individual needs becomes a fundamental factor in implementing strategies that ensure student success and strength the curricular and co-curricular activities to improve the program. The proposal of the student success standard is presented.

A curriculum supported in the analysis and synthesis of information allowing to take effective actions to mitigate the risk and vulnerability in the student population; with strategies focused on the prevention of drop out and that guarantee student success.

Description: A CDIO program seeks the integration of personal and interpersonal skills with product, process, and system building skills, as well as disciplinary concepts. Training in these competences should be gradual and start from the first semesters of the program. Student will be exposed to different experiences in order to reach proficiency levels associated with learning outcomes established by the curriculum. The achievements of each student in the process will be systematically assessed and its evaluation is associated with their performance in the program. Student success is a reflection of such performance and ideal conditions are necessary for the student to travel along the curricular route. Ensuring student success requires a continuous analysis of the academic, personal, socioeconomic and demographic information of the students. It is also necessary to propose strategies for the prevention of drop out, risks and vulnerability. The reality of each student depends on their location on the curricular path, their strengths and weaknesses. The differences and characteristics of each stage require differentiated learning contexts and particular support to ensure their success in training.

Rationale: A CDIO curriculum is focused on the student, their realities and needs. It recognizes the transitions that occur from the first year to the stages before graduation. It seeks the assurance of learning. It also prevents student drop out and develops strategies to motivate retention. It promotes the success of its students according to their realities and is managed from the analysis of the information from the academic community.

***Rubric**:*

Scale	Criteria
5	Accompanying programs and risk models optimize the program management processes and their continuous improvement dynamics
4	There is documented evidence of the intervention and accompaniment of students in their transition
3	An accompanying program is implemented including differential strategies for transition, risk models and vulnerability.
2	There is an explicit plan to generate dropout prevention schemes and also differentiated routes in each student transition.
1	The need to adopt a culture of risk prevention and student vulnerability based on the information of the academic community is recognized and there is a plan to establish the risk model in the program.
0	There is no plan to prevent desertion and facilitate student success.

CONCLUSIONS

The implementation and operation of a curriculum inspired by the CDIO initiative is guided by the 12 standards. This route starts once the programs are addressed with the philosophy CDIO acting as context of education (Standard 1). A curriculum aimed at the integration of skills from the first year is developed. This is described through learning outcomes (Standards 2, 3 and 4), in which students are exposed to design and implementation experiences in innovative work spaces (Standards 5 and 6). Teaching and learning methods are reviewed and updated (Standards 7 and 8). Clear strategies for development of the professors are proposed (Standards 9 and 10). Finally, it is proposed clear models of assessment and evaluation of the program (Standards 11 and 12). These last standards show the academic performance of the students (Brodeur, B., 2005), which is a process that is explained not only in the curricular structure but also in the particularities of a diverse population. Knowing the characteristics of the students becomes a vital action in the process of the operation and the curricular management. The assurance of learning as a measure of student success transcends academic variables. It includes also other variables such as socioeconomic conditions, personal realities, abilities, strengths and weaknesses of students. The analysis of these variables, the culture of accompanying at each stage and risk management become processes that must be articulated in the vision of a CDIO program. This articulation has generated the need to formalize the path of action associated with student success, through a new standard. This standard takes into account the aforementioned elements and the gradualness of their application in an institution.

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BIOGRAPHICAL INFORMATION

Alejandra Gonzalez, Ph.D is an Associate Professor in the Department of Electronics Engineering at the Pontificia Universidad Javeriana, Bogotá, Colombia. Since 2015, she has been the Head of the Electronics Engineering Program. Alejandra's research interests include embedded systems, digital systems design, high-level systems design, artificial intelligence, robotic and curricular management.

David Barrera, MSc is an Assistant Professor at the Industrial Engineering Department at the Pontificia Universidad Javeriana, Bogotá, Colombia. Since 2015, he has been the Head of the Industrial Engineering Program. Her research interests include: applied operations research, and curricular management.

Maria Patricia León, MSc is an Assistant Professor at the Civil Engineering Department at the Pontificia Universidad Javeriana, Bogotá, Colombia. Since 2012, she has been the Head of the Civil Engineering Program. Her research interests include: materials construction behavior, and curricular management

Mariela Curiel, PhD is an Assistant Professor at the Systems Engineering Department at the Pontificia Universidad Javeriana, Bogotá, Colombia. Since 2016, she has been the Head of the Systems Engineering Program. Her research interests include: distributed systems, computer performance evaluation, mobile computing and operating systems and and curricular management.

Luis David Prieto, PhD is an academic and researcher, dedicated to education and university management. He is an electronic engineer from the Pontificia Universidad Javeriana; Specialist in Engineering Management Systems from the same university and Ph.D in Computer Engineering and Systems from the Polytechnic of Turin. He is currently the Academic VicePresident of the Pontificia Universidad Javeriana.

Corresponding author

Dr. Alejandra Gonzalez
Pontificia Universidad Javeriana
Cra. 7 # 40 - 62
Bogotá, Colombia
+57 1 3208320
agonzález@javeriana.edu.co

CDIO IMPLEMENTATION

2

DESIGN THINKING FOR CDIO CURRICULUM DEVELOPMENT

Chong Hwa Lee and Linda Lee

Singapore Polytechnic International, Singapore

Natha Kuptasthien

Rajamangala University of Technology Thanyaburi, Thailand

ABSTRACT

Design Thinking (DT) is a human-centric approach to designing product, process, system and services. This paper aims to show how DT methodology and principles can assist curriculum developers empathise and gain deep understanding of their students. Insights on students' deep needs and learning behaviours can inspire curriculum development and teaching approaches that better engage students in active learning. The thematic Advancing CDIO curriculum development approach involves 4 themes, namely Mapping, Enhancing, Innovating, and Sustaining. For mapping the focus is on ensuring the continuous relevance of the curriculum. This involves conducting environmental scanning to better understand what are the emerging trends and the arising opportunities and challenges. Insights on the forces driving the changes for future of work help to determine and define the future skills expected of graduates. For enhancing CDIO skills, it is set in the context of Conceive-Design-Implement-Operate (CDIO) real-world systems and products. The emphasis is on enhancing students learning experience in a multi-disciplinary environment where students learn to work and collaborate with students from different disciplines to develop a project. The third Advancing CDIO theme on innovating teaching and learning approaches as well as learning space design explores how pedagogy and space design could be integrated to create conducive learning space that supports learning. Lastly, the sustaining phase describes how to determine the requisite resources and capabilities to consistently deliver quality CDIO programmes. The paper also shares the experiences gained from implementing engineering and non-engineering programmes through applying the design-led approaches in developing CDIO curriculum.

KEYWORDS

Design thinking, curriculum development, mapping CDIO skillsets, multi-disciplinary project, innovating CDIO learning and space, standards: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12

INTRODUCTION

As the CDIO regional centre in Asia, Singapore Polytechnic (SP) showcases a model for transforming engineering education that other Institutions of Higher Learning (IHLs) in Asia can draw insights, learn and adapt. SP is keen and willing to share its CDIO experience and to assist other universities implement the CDIO framework. SP has shared its CDIO experiences with many IHLs in Asia and these CDIO capability development programmes that have been implemented were supported and funded by Temasek Foundation International (TFI). With the introduction of CDIO, these participating institutions shared common experiences of higher motivation and engagement of students. They also encountered challenges such as understanding of the CDIO framework, implementation of the framework, buy-in from faculty members and workspace availabilities. (Lee et al., 2015)

Rajamangala University of Technology Thanyaburi (RMUTT), as the first CDIO collaborator in Thailand, has started introducing and applying the Conceive, Design, Implement, and Operate (CDIO) Framework for Re-Thinking Engineering Education since 2013 through a collaboration with SP that was supported by TFI. The institution is fully committed to the adoption and implementation of CDIO framework. RMUTT has established the quality management framework with CDIO as a foundation to produce hands-on professional graduates. Currently, 12 programmes from 5 faculties: Engineering, Business Administration, Mass Communication Technology, Architecture and Thai Traditional Medicine College, have fully adopted the CDIO framework. Industrial Engineering was the pioneer programme to adopt CDIO. (Kuptasthien et al., 2014).

In recent years, SP has developed expertise in Design Thinking (DT) human-centred approach to problem solving that drives creativity and innovation. The key to this process is empathising with the users' needs to generating innovative solutions. SP has already incorporated DT in the CDIO framework to enhance the "Conceive & Design" processes. Here, SP experimented with applying DT methodology and principles to strengthen curriculum development as a way to "Advancing CDIO" implementation. For simplicity this approach is called "Advancing CDIO". SP also shared this approach with the network of Rajamangala University of Technology (RMUTs) with the support of TFI.

This paper aims to:

1) Show how DT can assist the curriculum developers gain deep understanding of their students. Insights on students' deep needs and learning behaviours inspire curriculum development and teaching approaches that better engage students in active learning.
2) Highlight how the Advancing CDIO approach with its four themes, namely Mapping; Enhancing; Innovating; and Sustaining serve as a guide for effective curriculum development.
3) Demonstrate with examples from both engineering and non-engineering programmes, how this Advancing CDIO approach guides curriculum development.

LITERATURE REVIEW

Design Thinking (DT) is a human-centred approach to designing product, process, system and services. Many authors around the world have applied DT methodology in their teaching and learning practices as it promotes collaborative teamwork and communication along with critical and creative thinking skills. Some literatures are listed below:

A self-directed human-centric software engineering capstone course at Lappeenranta University of Technology, Finland, has effectively supported students with more hands-on and minds-on for the problem-based curriculum. (Palacin-Silva et al., 2017)

Computer Science and Software Engineering courses at a Federal University of Amazonas in Brazil implemented DT as an analytical and creative process to prepare students for the software development industry. The experience showed that DT encouraged students to come up with innovative and creative features for the application and improved the interaction among team members. (Valentim et al., 2017)

Multidisciplinary teams of students from engineering, design and art faculties at Shenka College of Engineering and Design in Israel have experienced using DT for product design practices. (Levy, 2017)

Darrin and Devereux (2017) at John Hopkins College of Applied Physics, USA has explored the incorporation of DT and Agile Manifesto in generic system engineering steps for system development life-cycle. The benefits of these new techniques will help systems engineering stay relevant and keep up with rapidly advancing technologies and intense competition environment.

The United States Air Force Academy, USA has adopted project-based learning and DT to achieve their educational outcomes. Their goal is to produce future digital-age military officers and government thinkers who can drive innovation with human-centric design approach. (Collins & Chiaramonte, 2017)

Suzuki (2016) investigated a novel approach of entrepreneurship education based on design thinking. Connections of design thinking courses with technology commercialization programme will benefit in the creation of a new key industry.

DT has been variously implemented by the CDIO community. At SP, DT has been infused into the CDIO framework in the Design-Built-Test concept and capstone-design projects. Here, the students have the opportunities to practice teamwork and communication skills along with creative and critical thinking (Fai, 2011). Yew et al (2016) showed the application of DT in conceive and design phases in Engineering Design and Business Project at SP. Kanazawa Technical College in Japan teaches DT in the curriculum with design methods, engineering management and graduation research. Learning Express[1] programme and mini-hydro power generation contest for extracurricular projects (Ito et al., 2015). CDIO framework and Design Thinking help raise the intrinsic motivation of the student to be innovative and try new ideas and challenges. (Leong, 2016).

Literatures showcase several applications and implementation of DT in teaching and learning, product design, capstone project, extra curriculum activities. However, to the authors' knowledge, there are very few literatures showing application of DT in curriculum development. McKilligan et al. (2017) used DT as a catalyst for changing teaching and learning. Faculty members redesigned courses and pedagogical approaches. One of the few literatures is a paper written by Kemp and Klaassen (2016) to envision engineering education 2030 for TU Deft. DT method explored questions regarding what future engineers should learn in higher engineering education in 2030. SWOT analysis was conducted to identify boundary conditions. The ideation stage revealed four future engineering students profiles: the Specialist, the System Integrator, the Front-end Innovator and the Contextual Engineer. An engineering and research environment called the Hubs encourage interdisciplinary learning. Last point of the findings is that common languages for future engineers consist of Mathematics, Digital literacy (data analytics, programming), Design skills, Academic communication, Engineering ethics and Collaborative and interdisciplinary teamwork.

[1]Learning Express (LeX) programme is an international Social Innovation Programme by Singapore Polytechnic that provides students with the opportunity to experience the natural world, learn new skills, make meaningful new friendships and rediscover yourselves through out-of-classroom learning.

DESIGN THINKING

This paper aims to show how DT can assist the curriculum developers gain deep understanding of their students. Insights on students' deep needs and learning behaviours inspire curriculum development and teaching approaches that better engage students in active learning. DT begins with empathizing with students' needs and challenges. This involves conducting observations and **Deep User Interviews** to uncover students' deep needs, motivations and pain-points. The open-ended interview questions were used to ask about their hopes, frustrations, needs, feelings, and desires, all of which will inspire ideas that improve student learning experience (including learning space design). Figure 1 shows an interview session of a student from the Tourism and Hotel Management programme. The next step, in **Needs Finding,** is to transform the observation and interview data into meaningful insights to uncover deep user needs. The interview transcripts were deconstructed into key information, quotes, and further clustered to identify common themes as shown in Figure 2. To help the programme committee focus on their students' needs, motivations, and challenges, **Student Persona** was developed to humanise the target users. Persona is a fictional character developed from interview outcomes that can help represents the student group.

Figure 1. Deep user interview (Tourism and Hotel Management Programme)

Figure 2. Deconstruct interviews into key information

ADVANCING CDIO CURRICULUM DEVELOPMENT

The Advancing CDIO curriculum development approach comprises 4 themes: Mapping; Enhancing; Innovating; and Sustaining. These 4 themes can be used to guide the institutions to enhance and strengthen CDIO implementation in addressing these 4 education concerns, namely: ensuring continuous relevance of curriculum, meeting the professional standards of graduates, innovating teaching and learning approaches, and strengthening the quality of education. This thematic approach challenges institutions to explore and innovate guided by the four principles of Future-Focused, Purpose-Driven, Design-Led and Quality-Minded.

Mapping

Mapping focuses on ensuring curriculum relevance in the face of rapidly changing environment. It highlights the importance of gaining insights on the future landscape so as to achieve a better understanding of the emerging trends and the arising opportunities and challenges. The goal is to gain broad and deep background knowledge of the forces driving the changes that influence the future of work and future skills expected of graduates. Figure 3 shows the Mapping process which includes STEEP analysis, identifying new competencies, determining graduate attributes and CDIO skillsets mapping.

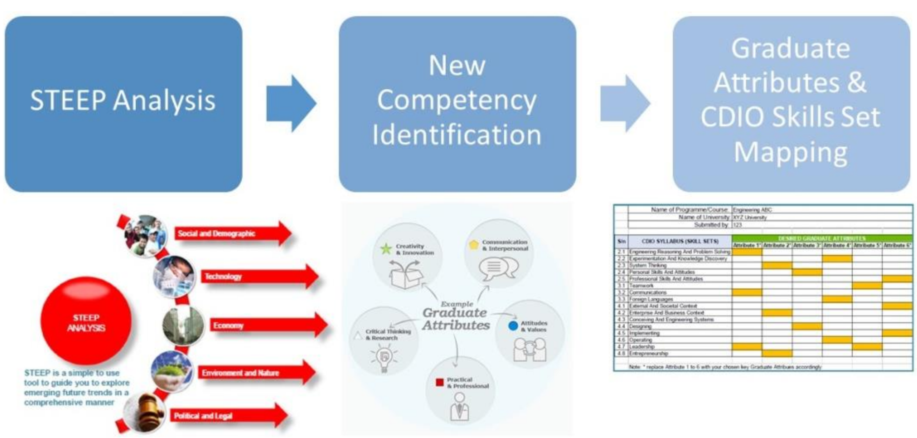

Figure 3. Mapping Phase

STEEP Trends Analysis

STEEP Analysis tool is a well-known framework used to explore future trends and their implications. Emerging mega trends are explored through these 5 categories: Social & Demographic, Technology, Economic, Environment & Nature, Political & Legal. The programme committee applied the STEEP framework to research and analyse the future trends for their industries.

Define the Future Graduate Attributes

Anchored in future trends, the programme committee analysed the opportunities and challenges as well as the future of works the students will encounter in this future reality. Insights on this future reality help to determine what are the desired future graduate attributes, which include attitudes, mindsets, skills and knowledge, may be needed to meet the future opportunities, challenges and future of works.

Mapping CDIO Skillsets with Future Graduate Attributes

The CDIO Syllabus is then mapped with the desired future-ready graduate attributes to determine which CDIO skillsets to emphasise and strengthen. The identified CDIO skillsets are then purposefully integrated into the programme curriculum and incorporated into the learning outcomes.

Enhancing

For enhancing CDIO skills, it is set in the context of Conceive-Design-Implement-Operate (CDIO) real-world systems and products. In line with DT principles which advocate multidisciplinary teamwork, the emphasis is on enhancing students learning experience in a multi-disciplinary environment where students learn and collaborate with students from different disciplines to develop a project. The enhancement of CDIO skillsets focuses on developing personal and interpersonal skills through cross-functional, multi-disciplinary projects (MDP) to foster resourceful professional graduates. The MDP is a student-project prepared by the teaching team. The students received a project brief before the commencement of the project. In addition, the process of completing a project provides opportunities for students to develop interpersonal skills and the opportunity to network with professionals who support them in the projects. Figure 4 shows 5 steps for planning MDP.

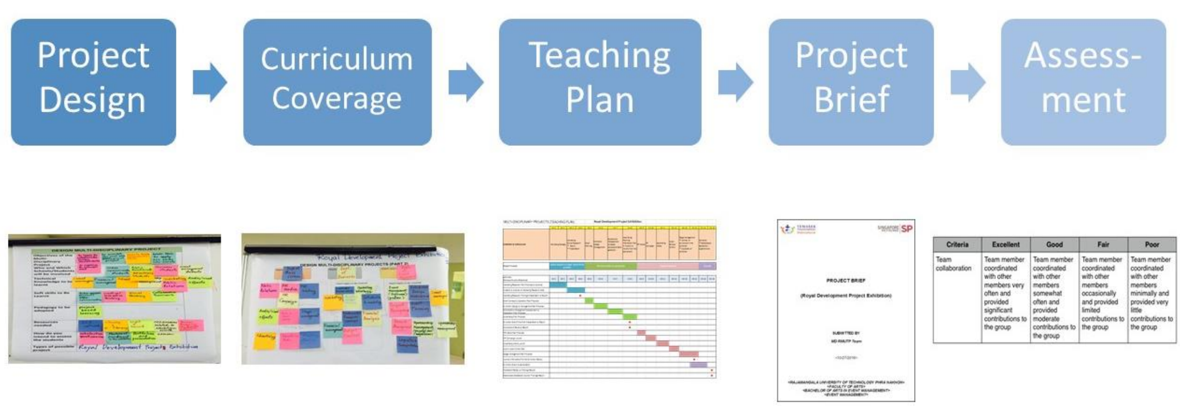

Figure 4 shows 5 steps for planning MDP.

The process begins with *Project Design* emphasizing on the development and design of MDP projects based on industry needs relevant to the programme. Grounded on solving real-world problems, MDP facilitate students to apply and acquire the range of requisite skills including personal and interpersonal skills. This is followed by *Curriculum Coverage* by identifying the range of topics and skills from each discipline involved in the project to allow the faculty member in-charge of MDP to map out the topics and skills that students need to learn from each discipline. This process ensures the MDP project curriculum covers all the requisite knowledge, skills and experiences that students are expected to gain. A weekly MDP *Teaching Plan* is then plotted with key milestones and activities. With that both students and MDP teaching staff can monitor and evaluate their progress. A MDP *Project Brief* is then prepared by lecturer that clearly spells out the project objectives, desired learning outcomes, the scope of the project, the different phases of the project, and the stakeholders relevant to the MDP project .This project brief serves as a guide for the entire project, from defining user requirements to completion ,Finally .MDP teaching staff design appropriate *assessments* given the nature of MDP projects and supported by assessment rubrics to ensure student performance is fairly evaluated across the disciplines involved.

Innovating

The third Advancing CDIO theme on innovating teaching and learning approaches as well as learning space design explores how pedagogy and space design could be integrated to create conducive learning space that supports learning. This design-led process encourages teaching faculty to explore and design effective teaching and learning experience drawing insights and inspiration from the student persona to better understand current student's needs, challenges and aspirations. Figure 5 represents components of innovating process with teaching and learning approach and learning space design.

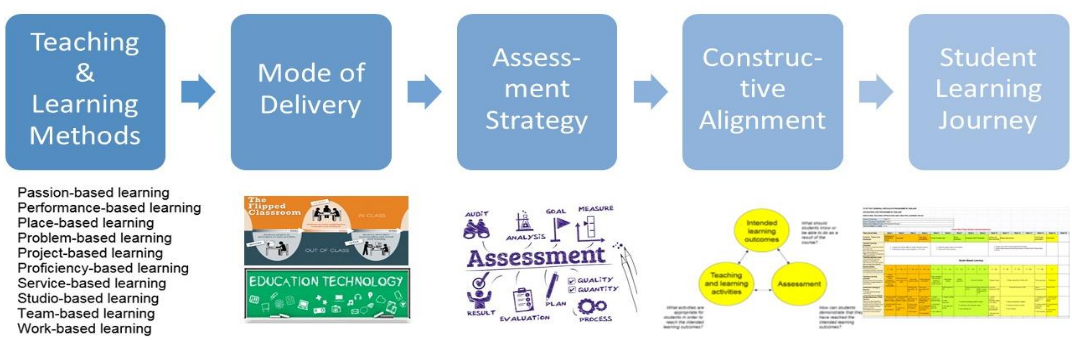

Figure 5. Innovating Phase

Here, the CDIO incorporated learning outcomes are first clearly defined on what the students will be able to do and what they should become. Then appropriate teaching approaches with relevant assessment methods are developed to address students' achievement of the desired learning outcomes and standards.

Create Conducive Learning Space

This design-led process to creating conducive learning space involves 5 steps, each supported by specific tools and techniques as shown in Figure 6.

Figure 6. Steps and techniques for Learning Space Design

Step 1: Visual Mapping is an effective way to illustrate the desired spatial atmosphere for the learning space. To stimulate creativity and idea generation, a visual "mood" board with a large quantity and variety of pictures is used. Faculty members select those visuals that best articulate the spatial atmosphere they envision the space to provide.

Step 2: Concept Development is defined by using Metaphors or Themes. This process involves identifying and defining the central themes or metaphors that best illustrate the overall concept of the learning space where the planned learning activities and student learning experience would take place.

Step 3: Ideal User Journey is illustrated by using Storyboarding. This step requires sketching images that illustrate students' learning experience in the learning space. The storyboard can explain the atmosphere of learning space one by one. Every perspective can show details of the functions and the relationship between the students and the learning activities.

Step 4: Space Plotting aims to visually zone the relevant physical space where the different planned learning activities may take place within the learning space. One approach is to use "bubble diagram" to zone or delineate where a particular learning activity would take place.

Step 5: Prototyping the Desired Learning Space is to transform the sketches into tangible, physical prototypes of the space. Prototyping allows the developing and testing of the space ideas at an early stage before large-scale resources are committed to build the learning space.

Sustaining

The sustaining phase focuses on the supportive and sustaining strategies needed to instil quality–mindset and culture amongst academic staff and across the entire institution. This may include a commitment to professional development of teaching staff and providing the requisite resources essential for advancing CDIO initiatives in the institution. Another contributing factor to sustaining CDIO initiative is to promote positive relationships and activities that engage teaching staff to collaborate with one another, as well as with peer mentors and academic mentors. The community of practice can lead to sustaining the change. It involves a group of educators/lecturers who meet regularly, shares expertise, and works collaboratively to improve teaching skills and the academic performance of students. Specific activities and goals of learning community may vary from institution to institution.

Example of Engineering Program: Industrial Engineering (IE)

Mapping: The program committee conducted STEEP Analysis and defined IE program outcomes and graduate attributes to align with Thailand 4.0 scheme (responding to the Global Industrial 4.0). Enhancing: Deep Users' interviews were conducted to better understand students' learning behaviors and their needs in order to help the program committee developed a Learner Centered curriculum. The students are assessed not only on their technical knowledge, but also communication and teamwork skills in the MDP. Innovating: The IE department explores how pedagogy and space design could be integrated to create conducive learning space that supports learning. Fab Lab as an innovative workspace to all students was developed after this exercise. Sustaining: Faculty development plan is developed annually to improve professional and teaching skills. The faculty members were encouraged to collaborate with industries. IE program was accredited by Thailand Accreditation Board of Engineering Education (TABEE) on 13-15 December 2017. It will be recognized as the 1st IE programme with outcome-based accreditation in Thailand. The Council of Engineers (Thailand) wish to submit to be a member of the Washington Accord in 2018. CDIO implementation since 2013 has facilitated the department in ensuring a smooth preparation for the programme accreditation.

Example of Non-Engineering Program: Tourism and Hotel Management

The Advancing CDIO thematic approach of Mapping, Enhancing, Innovating and Sustaining was adapted and applied to the "Tourism and Hotel Management" programme curriculum in inspiring the programme committee to rethink, develop and enhance its programme curriculum. Consequently, several courses have been developed for CDIO implementation this current academic year. The Innovating CDIO in teaching and learning has been integrated with Thai Qualification Framework (TQF) for planning the course. The team has observed a gradual positive change of their colleagues' attitudes towards CDIO. They found that CDIO concept is very beneficial for both of teachers and students. From the teachers' perspective, they can apply the CDIO framework and methodology in their classes, including designing the curriculum. In addition, students are more motivated and better engaged through the applied, hands-on active experiential learning.

CONCLUSION

This paper proposes a thematic Advancing CDIO approach to enhancing and strengthening CDIO implementation. This approach incorporates DT methodology and principles in understanding and empathising with students' needs and challenges. With the future reality in view, the future graduate attributes help determine which CDIO skillsets need further emphasis. For enhancing CDIO skillsets, MDP can deepen student learning experience and strengthen students learn and develop requisite skills including personal and interpersonal skills. Active teaching and learning along with learning space innovation can increase intrinsic motivation and support students' learning in the Innovating process. For sustaining CDIO initiatives, it is important for the institution to encourage the community of practice in sharing and exchanging CDIO implementation experiences. Future work can focus on comparative studies among engineering and non-engineering programmes in the network of RMUTs regarding areas of improvement, challenges of the implementation and learning points.

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BIOGRAPHICAL INFORMATION

Chong Hwa, Lee (chonghwa.spi@gmail.com) is currently a Principal Consultant in Design Thinking and Education with Singapore Polytechnic International (SPI). He has over 30 years of career experience with a good track record in designing innovative educational models, quality courses and successful programme implementation. As a certified Design Thinking practitioner by Rotman DesignWorks, University of Toronto, he is a pioneer in infusing Design Thinking in business education. He has consulted, led and facilitated many Design Thinking and Education projects and workshops in Singapore and overseas. Chong Hwa graduated with a Bachelor of Social Sciences (Hons) from the National University of Singapore and a Master in International Business (President's Hons) from the Institute Surperieur de Gestion (ISG), France.

Linda Lee (lindalee.spi@gmail.com) is currently a Principal Consultant with Singapore Polytechnic. Since 2012, Linda has conducted many CDIO and other educational capability development programmes in countries including Mongolia, Malaysia, Indonesia, Vietnam, Thailand, Philippines, Korea and China. Prior to this, she was the Deputy Director from the School of Mechanical and Aeronautical Engineering and has been involved in the implementation of CDIO in Singapore Polytechnic since 2006. Linda graduated with a Bachelor of Science (1st Class Hons) and PhD in Information Technology in Machining from Loughborough University, United Kingdom.

Natha Kuptasthien is currently as assistant to president for International Relations and an associate professor at the industrial engineering department, faculty of engineering, RMUTT. She led a full CDIO implementation at RMUTT since 2013. She has conducted a number of CDIO introductory workshops for engineering and non-engineering programs, which expanded the CDIO network to 8 RMUTs and universities in Asia. Natha graduated with a Bachelor of Engineering in Industrial Engineering from Chulalongkorn University, Master of Science and PhD in Engineering Management from University of Missouri-Rolla, USA.

Corresponding author

Natha Kuptasthien
Rajamangala University of Technology Thanyaburi, RMUTT
39 Village No. 1, Rangsit-nakornnayok Road, Klong 6, Thanyaburi, Pathumthani, Thailand 12110
natha.k@en.rmutt.ac.th

3

CDIO FRAMEWORK AND SKILLSFUTURE: REDESIGN OF CHEMICAL ENGINEERING CURRICULUM AFTER 10 YEARS OF IMPLEMENTING CDIO

Sin-Moh Cheah, Katerina Yang

School of Chemical & Life Sciences, Singapore Polytechnic

ABSTRACT

This paper shares the experience of the Diploma in Chemical Engineering (DCHE) Course Management Team in using the CDIO Framework to help formulate its approach to redesign its DCHE curriculum to align it to the requirements of the SkillsFuture Initiative. The SkillsFuture Initiative was launched by the Singapore Government in 2015 and aimed at helping Singapore manufacturers improve their operations to remain competitive in the global marketplace, promoting lifelong learning by providing workers with avenues to deepen their existing skills and acquire new ones, so that they can stay relevant amid ever-changing workplace demands. It is the country's response to the challenge of Industry 4.0. Two key elements of SkillsFuture of relevance to education are the Skills Framework and Enhanced Internship. This paper first explains Chemicals 4.0 – the chemical industry's equivalent of Industry 4.0, and briefly summarises its implications for the chemical industry in general, and chemical engineering education in particular. Next, the paper shares how the CDIO approach is used to guide the curriculum review process, i.e. in addressing the questions of what knowledge, skills and attitudes are required for Chemicals 4.0. The outcome of the process is to establish a course structure that is able to meet the needs of learners in term of pre-employment training (i.e. students) as well as continuing education and training (i.e. adult learners). The paper then provides a summary of the authors' review of pertinent literatures to specifically address the need of the DCHE curriculum, narrowing the focus into the following knowledge areas: predictive asset management, process management and control, energy management, safety management, and production simulation. As for the skills and attitudes, the paper argues that most of the skills needed are already addressed in our "CDIO-enabled" curriculum. However, with the emphasis on Chemicals 4.0, some skills now take on greater importance, such as sense-making, data analysis, resource management and virtual collaboration. The paper then provides a summary of our revamp effort over the past 4 years since the last self-evaluation exercise in 2012 (i.e. from 2013-2016), and the plan for the next 4 years (2017-2020) to implement a new course structure based on a spiral curriculum. The paper concludes with a brief explanation on why a spiral curriculum is suitable for DCHE, and provides an approach to transition the existing curriculum to the spiral one.

KEYWORDS

Chemicals 4.0, Chemical Engineering, Spiral Curriculum, CDIO Standard 12

NOTE: Singapore Polytechnic uses the word "courses" to describe its education "programs". A "course" in the Diploma in Chemical Engineering consists of many subjects that are termed "modules"; which in the universities contexts are often called “courses”. A teaching academic is known as a "lecturer", which is often referred to a as "faculty" in the universities.

INTRODUCTION

The Diploma in Chemical Engineering (DCHE) from Singapore Polytechnic had adopted CDIO as the basis for revamping its curriculum since 2007 and its “CDIO-enabled” curriculum was introduced for the first time in April 2008 for students for the Academic Year 2008/2009 cohort. Since then, the course had been revised several times in response to changing socio-economic developments in Singapore affecting the educational sector. The details described in this paper, which arise as a result of the Singapore Government’s SkillsFuture Initiative, is by far the single largest change we have made since 2008. The SkillsFuture Initiative is a response to the increasing VUCA (volatile, uncertain, complex, ambiguous) world, accelerated by the advent of Industry 4.0. In terms of educational outcome this means meeting the requirements for technical and generic competencies (knowledge, skills, attitudes) as detailed in the Skills Framework (SF) for the industry sector the program is serving. It also means we need to have a course structure that is able to meet the needs of both existing students (in terms of Pre-Employment Training, or PET in short) and adult learners (in terms of Continuing Education and Training, or CET in short). This paper focuses on the effort by the DCHE Course Management Team in responding to these challenges. The sector DCHE is serving is the Energy & Chemicals (E&C) Sector, comprising companies producing bulk and commodity chemicals, specialty chemicals, gas and utilities, etc. Our students also found employment in the pharmaceutical industries. Our students typically found employment as Engineering Executives, Process Technicians, Process Analysts, etc.

CHEMICALS 4.0 – THE CHEMCIAL INDUSTRY’S RESPONSE TO INDUSTRY 4.0

The chemical industry’s equivalent of Industry 4.0 is often referred to as Chemicals 4.0. The chemical industry is typically characterized by continuous production as opposed to discrete production in other non-process industries. Another key feature is the industry’s significant asset intensity as well as logistics and energy cost (De Leeuw, 2017; Wehberg, 2015). Despite the different nature of the chemical industry’s production, Industry 4.0 is just as relevant. However, as argued by Wehberg (2015), the chemical industry’s specific characteristics need to be taken into account. The chemical industry operates in a global environment with a high degree of uncertainty and volatility, and faced the following challenges (GE, 2016):

- Coping with low oil prices without jeopardizing future performance
- Increasing technical complexity of asset mix that oil and gas companies are developing and operating
- Aging and turnover of industry’s workforce
- Regulatory concerns around health, safety and the environment

Chemicals 4.0 can potentially transform the chemical industry by promoting strategic growth and streamlining operations, across the entire value chain. There are opportunities for all stages of operations from upstream (e.g. oil exploration and production forecasting), to midstream (e.g. refining, conversion) and downstream (e.g. demand forecasting, facility integrity, commodity trading risk management and customer intelligence) (ATOS, 2016; SAS, 2014). All these are taking place because of the convergence brought about by Industry 4.0, e.g. in the areas of cloud computing, inexpensive sensors, progressive network availability, and big data analytics (IIC, 2015). With such convergence, many chemical companies can develop holistic solutions that integrate silos of information from suppliers, plant floor, sales and marketing, laboratory information management systems and third parties. Through advanced analytical techniques, companies can raise their productivity, manufacturers can increase efficiency and enhance product quality (Kaestner, 2016). Given the developments in Chemicals 4.0, the question for chemical manufacturers is not whether to enter into the fray by adopting Industry 4.0 connectivity and “smart” manufacturing technologies, but rather where to start (Elsevier, 2017). Chemicals 4.0 not only transforms how the chemical industry operates, it also reshapes the nature of the workforce and the skills and competencies required (Accenture, 2015). The next section explores the impact on chemical engineering education.

REDESIGNING THE DIPLOMA IN CHEMICAL ENGINEERING: FOCUS AREAS

As mentioned earlier, revision to the course structure is necessary to achieve a form of “blurring” between PET and CET; to accommodate both students (PET) and adult learners (CET) to equip them with the competencies needed in a Chemicals 4.0 world. The first author had demonstrated elsewhere that the CDIO Framework is compatible with the requirements of SkillsFuture (Cheah, 2018). Therefore, in reviewing and redesigning our DCHE curriculum, we use the tried-and-tested ‘standard’ CDIO approach, by focusing on the following key questions:

1. Need: What is the professional role and practical context of the profession?
2. Learning outcomes: What knowledge, skills and attitudes should students (and adult learners) possess as they graduate from our programs?
3. Curriculum, workspace, teaching, learning and assessment: How can we do better at ensuring that students and adult learners learn these skills?

Questions 1 and 2 can be addressed by referencing the E&C SF. It provides program owners, curriculum designers, etc with a comprehensive set of reference documents to review and plan their curriculum. Among these documents are the sector and employment information, career map and job roles, technical and generic skills and competencies. Detailed study of the E&C SF showed that while our 3-year program covered many of the required technical skills and competencies (TSCs) and generic skills and competencies (GSCs), there are certainly gaps in our curriculum. This is not entirely surprising, as the E&C Sector is very broad; and the advent of Chemicals 4.0 did introduce new knowledge, skills and competencies that chemical engineering graduates needed, in particular Internet of Things and data analytics. Specifically, 2 TSCs are included for the job role of employees in the E&C sector include the following: (1) Internet of Things (IoT) Management, and (2) Robotic and Automation Technology Application.

What are the new or enhanced knowledge needed?

It is obviously not possible for a 3-year program to address all the needs and changes in Chemical 4.0 presented earlier. After reviewing the relevant literatures, and consulting with our industry partners, we narrowed down our focus areas to the following:

Predictive Asset Management (Deloitte, 2016; Frost & Sullivan, 2016; SAS, 2014)

Using the continuous feed of data collected from sensors on critical equipment such as turbines, compressors, and extruders, advanced analytics tools can identify patterns to predict when a piece of equipment is likely to experience a specific failure and diagnose possible breakdowns. In doing so, smart equipment can send messages to plant operators about any required maintenance, potential breakdowns, and parts ordering and delivery schedules. By integrating data from a variety of process sources with knowledge and experience databases, operations can boost uptime, performance and productivity while lowering maintenance costs and downtime. This can enable manufacturers to evolve from scheduled or reactive repairs to predictive maintenance. This is also known as Asset Performance Management (GE, 2016).

Process Management and Control (Deloitte, 2016)

Process variability results from a variety of factors, starting from the quality of raw materials to variations in internal processes such as raw material dosing, temperature control, residence times, system fouling, and aging catalysts. Similar to predictive asset management, process management and control involves collecting structured and unstructured data via sensors from various sources such as the lab, alarms, and process equipment to help to identify patterns and deviations in chemical processes before they occur, as well as helping in operation optimizations, thus helping to maintain production stability.

Energy Management (Deloitte, 2016, Frost & Sullivan, 2016; GE, 2016, Guertzgen, 2016)

Energy costs contribute significantly to a chemical plant's production costs. A typical plant involves multiple activities and their interactions, and it is difficult for operators to select optimal operating conditions. The chemicals industry has a high degree of automation, and most plants monitor standard variables such as temperature, flows, tank levels, and pressures to derive optimal plant working conditions. Industry 4.0 technologies can augment these data points with additional information and enable control of non-standard process variables to improve energy efficiency.

Safety Management (Accenture, 2017b; Uktem, et al, 2013)

Big data from all the process measurements and alarms can be analysed and processed rapidly to extract crucial risk information, thus creating leading indicators of potential performance issues, such as shutdowns, accidents, incidents, and operational problems, hence provide indicators of the process risks. For example, frontline supervisors can make data-driven decisions to identify risks and respond quickly to problems.

Production Simulation (Deloitte, 2016; Lozowski, 2017)

Chemical companies are increasingly using 3D visualization e.g. augmented reality (AR) and/or virtual reality (VR) for training operators and maintenance staff. Trainees can "walk" across a simulated plant, "work" with the equipment and instruments, and "handle" safety situations. They can also collaborate with their peers, and individual and collective performances can be monitored by instructors. In addition to operator training and prognostics, AR/VR also helps operators prepare before the plant operations begin.

What are the new or enhanced skills needed?

Cheah & Leong (2018) had reviewed the relevance of the CIDO Syllabus in addressing the competencies needed in Industry 4.0. However, with the emphasis on Chemicals 4.0, especially with regards to IoT and data analytics in the key focus areas identified above, some skills now take on greater importance, such as sense-making, data analysis, resource management and virtual collaboration (Accenture 2017a, SSG, 2017). Table 1 shows a summary of the present status of our curriculum with regards to the coverage of knowledge and skills needed, along with very broad identification of the gaps.

Lastly, to address Question 3, we use the CDIO self-evaluation process to identify specific action items to guide the redesign effort. Table 2 shows the concise summary of work done in the last 4 years since the last self-evaluation exercise in 2012 (i.e. 2013-2016), and suggested plans for the next 4 years (i.e. 2017-2020).

Table 1. Chemicals 4.0 – Focus area for Diploma in Chemical Engineering

<table>
<tr><th>Description</th><th>Existing Coverage in
3-year DCHE Curriculum</th><th>New/Enhanced Skills
& Competencies</th><th>Gap in
Coverage</th></tr>
<tr><td>Predictive asset management</td><td>Not covered</td><td rowspan="3">Internet of Things applications, data analysis, sense-making, resource management</td><td>HIGH</td></tr>
<tr><td>Process management and control</td><td>Focus on process instrumentation and control, limited coverage on optimization</td><td>LOW</td></tr>
<tr><td>Energy management</td><td>Limited to heat integration</td><td>HIGH</td></tr>
<tr><td>Safety management</td><td>Focus on inherently safer design and plant safety system, limited coverage on occupational safety & health</td><td rowspan="2">As above, but also include virtual collaboration in AR/VR environment</td><td>MEDIUM</td></tr>
<tr><td>Production simulation</td><td>Focus on steady-state modelling for chemical process plant design.</td><td>MEDIUM</td></tr>
</table>

KEY CHANGES IN DCHE COURSE STRUCTURE: NEW SPIRAL CURRICULUM WITH ENHANCED INTERNSHIP

Cheah (2018) had earlier shared some ideas of how the CDIO Standards can be used to review and redesign an engineering curriculum vis-à-vis the needs of SkillsFuture. In this paper, we apply these ideas to the DCHE curriculum. The results of the self-evaluation exercise identified key areas in the curriculum that the Course Management Team can focus the redesign effort on. The 2 key outcomes are: a new course structure termed the spiral curriculum, and enhanced internship that will strengthen students' learning experiences. We first discuss enhanced internship here but only briefly. The remaining sections of this paper provide more information about spiral curriculum.

Enhanced Internship

Enhanced Internship (EI) is a key feature under SkillsFuture. It is "enhanced" in that it required longer duration (1 semester to a year), with structured learning plan, defined learning outcomes and mentoring by industry partners. DCHE introduced its EI in Semester 1, Academic Year 2015 as part of institution-wide initiative to embrace SkillsFuture. Specifically, we rationalized our modules and introduced a “5+1” course structure whereby students spend 5 semesters studying in campus, and 1 semester on EI. This was done ahead of the curriculum review and redesign, and our effort is focused on securing sufficient EI places with relevant companies in the E&C Sector for our students. Details of our EI implementation will be shared in separate paper at a later date. Suffice to note that EI is now part of the newly designed course structure termed spiral curriculum which is discussed next.

What is Spiral Curriculum?

Spiral curriculum is a concept first proposed by Bruner (1960). It is an approach to education that introduces key concepts to students at a young age and covers these concepts repeatedly, with increasing degrees of complexity. This approach is also known as a "spaced" or "distributed" approach. It contrasts with "blocked" or "massed" curricula, which do not introduce difficult concepts until the student has reached a higher level of education.

Table 2. Outcome of DCHE CDIO Self-Evaluation vs SkillsFuture

<table>
<tr><td>CDIO Standard 1 – The Context</td><td colspan="3">Adoption of the principle that product, process, and system lifecycle development and deployment -- Conceiving, Designing, Implementing and Operating -- are the context for engineering education</td></tr>
<tr><td>Rating from Self-Evaluation</td><td>2008: 3</td><td>2012: 5</td><td>2016: 5</td></tr>
<tr><td colspan="4">Brief Summary of Selected Efforts (from 2013 to 2016)
Maintain existing efforts to communicate CDIO to new students</td></tr>
<tr><td colspan="4">Action Plans for Next 4 Years (2017 – 2020)
To extend the CDIO context for engineering education to workplace learning via Enhanced Internship (EI) at supporting companies. More elaboration of EI is provided in the text.</td></tr>
<tr><td>CDIO Standard 2 – Learning Outcomes</td><td colspan="3">Specific, detailed learning outcomes for personal and interpersonal skills, and product, process, and system building skills, as well as disciplinary knowledge, consistent with program goals and validated by program stakeholders</td></tr>
<tr><td>Rating from Self-Evaluation</td><td>2008: 3</td><td>2012: 4</td><td>2016: 4</td></tr>
<tr><td colspan="4">Brief Summary of Selected Efforts (from 2013 to 2016)
More modules now have learning outcomes included at activity/task levels, e.g. in lab manuals.</td></tr>
<tr><td colspan="4">Action Plans for Next 4 Years (2017 – 2020)
To integrate newly identified knowledge and skills needed (Table 1) into suitable modules (Standard 3) with existing/new activities (Standards, 7 and 8), as well as into EI as appropriate.</td></tr>
<tr><td>CDIO Standard 3 – Integrated Curriculum</td><td colspan="3">A curriculum designed with mutually supporting disciplinary courses, with an explicit plan to integrate personal and interpersonal skills, and product, process, and system building skills</td></tr>
<tr><td>Rating from Self-Evaluation</td><td>2008: 3</td><td>2012: 4</td><td>2016: 4</td></tr>
<tr><td colspan="4">Brief Summary of Selected Efforts (from 2013 to 2016)
Switched to sequential diploma structure since AY13/14. Problem-based learning piloted as assignment in Environmental Engineering in AY13. Introduced integrated laboratory, integrated assignment & integrated mid-semester test for Year 2. EI (22 weeks) introduced in Semester 1, Academic Year (AY) 2015. To-date, 2 runs of EI had been completed. See also Standard 5.</td></tr>
<tr><td colspan="4">Action Plans for Next 4 Years (2017 – 2020)
To redesign the DCHE course structure to align to career map in the E&C SF, via a spiral curriculum, and closing gaps (Table 1) identified. To review EI for greater integration with the rest of DCHE curriculum. See also Standards 3 and 7 and discussion in main body of paper on approach taken.</td></tr>
<tr><td>CDIO Standard 4 – Introduction to Engineering</td><td colspan="3">An introductory course that provides the framework for engineering practice in product, process, and system building, and introduces essential personal and interpersonal skills</td></tr>
<tr><td>Rating from Self-Evaluation</td><td>2008: 3</td><td>2012: 4</td><td>2016: 5</td></tr>
<tr><td colspan="4">Brief Summary of Selected Efforts (from 2013 to 2016)
Introduced activity on to promote greater awareness of career pathways, roles and responsibilities.</td></tr>
<tr><td colspan="4">Action Plans for Next 4 Years (2017 – 2020)
To include introduction to Internet of Things, with activities focusing on importance of sense-making and data analysis. These will be enhanced in other activities (see Standards 7, 8) as well.</td></tr>
</table>

Table 2. (cont'd)

<table>
<tr><td>CDIO Standard 5 – Design-Implement Experiences</td><td colspan="3">A curriculum that includes two or more design-implement experiences, including one at a basic level and one at an advanced level</td></tr>
<tr><td>Rating from Self-Evaluation</td><td>2008: 3</td><td>2012: 4</td><td>2016: 4</td></tr>
<tr><td colspan="4">Brief Summary of Selected Efforts (from 2013 to 2016)
EI, introduced in AY2015 requires that students complete company project(s). Strengthened teaching of chemical product design, with emphasis on sustainable development.</td></tr>
<tr><td colspan="4">Action Plans for Next 4 Years (2017 – 2020)
To retain existing chemical product design pathway as 3 modules running from Year 1 to Year 3 for the spiral curriculum, leading to the capstone final year project in Year 3 as part of integrated curriculum. To review coverage of process simulation leading to Plant Design Project in existing core modules, as the topics may be re-distributed to new modules. See also Standard 7.
To strengthen workplace learning during EI, especially via company project(s) by align learning outcomes from EI with E&C SF (Standard 2).</td></tr>
<tr><td>CDIO Standard 6 – Engineering Workspaces</td><td colspan="3">Engineering workspaces and laboratories that support and encourage hands-on learning of product, process, and system building, disciplinary knowledge, and social learning</td></tr>
<tr><td>Rating from Self-Evaluation</td><td>2008: 3</td><td>2012: 3</td><td>2016: 3</td></tr>
<tr><td colspan="4">Brief Summary of Selected Efforts (from 2013 to 2016)
Budget secured in AY16 to renovate W318, preliminary concept and floor plan done for a new Energy & Chemicals Training Centre. Already went ahead with renovation work, and procurement of new integrated pilot plant.</td></tr>
<tr><td colspan="4">Action Plans for Next 4 Years (2017 – 2020)
To follow-up on work done as noted above and redesign new learning activities to align with TSCs and GSCs for E&C SF. In addition, to explore use of AR/VR and EI to leverage on company factory floor or laboratory to complement in-campus facilities. Together with Standard 7, the former is especially desirable in the development of identified skills and competencies (see Table 1).</td></tr>
<tr><td>CDIO Standard 7 – Integrated Learning Experiences</td><td colspan="3">Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal and interpersonal skills, and product, process, and system building skills</td></tr>
<tr><td>Rating from Self-Evaluation</td><td>2008: 3</td><td>2012: 4</td><td>2016: 4</td></tr>
<tr><td colspan="4">Brief Summary of Selected Efforts (from 2013 to 2016)
Introduced Integrate Laboratories for Year 2. Introduced virtual collaboration in Year 3 module Plant Safety & Loss Prevention, taught using flipped learning format. Students work collaboratively in class and also during home-based learning (simulated campus closure for 1 week) on case studies and other class activities using Google Doc or Google Slide.</td></tr>
<tr><td colspan="4">Action Plans for Next 4 Years (2017 – 2020)
To review activities under existing modules and redistributed as appropriate to new modules in the spiral curriculum (see Standard 3). Where suitable, to also integrate new topics in Table 1 to close the gaps. Also, to introduce activities in virtual learning environment (VLE) using AR/VR (Schuster, et al, 2015) in suitable modules. See also Standard 8.</td></tr>
</table>

Table 2. (cont'd)

<table>
<tr><td>CDIO Standard 8 – Active Learning</td><td colspan="3">Teaching and learning based on active experiential learning methods</td></tr>
<tr><td>Rating from Self-Evaluation</td><td>2008: 3</td><td>2012: 4</td><td>2016: 4</td></tr>
<tr><td colspan="4">Brief Summary of Selected Efforts (from 2013 to 2016)
Flipped classroom introduced for selected modules. Increased use of EdTech tools such as Socrative, Kahoot, Padlet, etc to enhance student participation in class.</td></tr>
<tr><td colspan="4">Action Plans for Next 4 Years (2017 – 2020)
To continue encouraging more adoption of flipped classroom in the spiral curriculum, especially on topics related to understanding factual information; to continue with more usage of EdTech tools. Also, to introduce activities on IoT and using AR/VR (see also Standards 6, 7).</td></tr>
<tr><td>CDIO Standard 9 – Enhancement of Faculty Competence</td><td colspan="3">Actions that enhance faculty competence in personal and interpersonal skills, and product, process, and system building skills</td></tr>
<tr><td>Rating from Self-Evaluation</td><td>2008: 3</td><td>2012: 4</td><td>2016: 5</td></tr>
<tr><td>CDIO Standard 10 – Enhancement of Faculty Teaching Competence</td><td colspan="3">Actions that enhance faculty competence in providing integrated learning experiences, in using active experiential learning methods, and in assessing student learning</td></tr>
<tr><td>Rating from Self-Evaluation</td><td>2008: 3</td><td>2012: 4</td><td>2016: 4</td></tr>
<tr><td colspan="4">Brief Summary of Selected Efforts (from 2013 to 2016)
Introduced Academic Mentor Scheme where appointed lecturers serve as mentors to assist Course Chair in curriculum review, as well as fellow lecturers in adopting new pedagogy, module re-design (e.g. using CDIO) and/or use of EdTech tools.</td></tr>
<tr><td colspan="4">Action Plans for Next 4 Years (2017 – 2020)
To identity training opportunities for lecturers to develop facilitation skills in learning of GSCs such as sense-making, transdisciplinary thinking, etc. Training also needed on technological competencies in order to interact with students in VLE. This includes not only design of VLE but also experience in digital coaching and joint problem solving in virtual worlds, which is becoming a mode of teaching to tutor and moderate groups of students in VLEs (Richert, et al, 2015)</td></tr>
<tr><td>CDIO Standard 11 – Learning Assessment</td><td colspan="3">Assessment of student learning in personal and interpersonal skills, and product, process, and system building skills, as well as in disciplinary knowledge</td></tr>
<tr><td>Rating from Self-Evaluation</td><td>2008: 2</td><td>2012: 3</td><td>2016: 3</td></tr>
<tr><td colspan="4">Brief Summary of Selected Efforts (from 2013 to 2016)
Use of survey instrument not started. Assessment of knowledge and skill transfer via Integrated Assignment (see work on Standard 3)</td></tr>
<tr><td colspan="4">Action Plans for Next 4 Years (2017 – 2020)
At this moment, we are using a standard template for assessment on EI. We will continue to review execution of EI for the AY17 cohort whose EI will end in February 2018; and customize the EI to DCHE needs, especially in relation to the TSCs and GSCs for the E&C SF.</td></tr>
</table>

Table 2. (cont'd)

CDIO Standard 12 – Program Evaluation	*A system that evaluates programs against these twelve standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement*		
Rating from Self-Evaluation	2008: 2	2012: 3	2016: 4
Brief Summary of Selected Efforts (from 2013 to 2016) Integrated the CDIO self-evaluation process into AQMS (Academic Quality Management System) to help with course-level review, and cascaded the review down to module level. Diploma was successfully re-accreditation by IChemE UK in May 2017.			
Action Plans for Next 4 Years (2017 – 2020) To obtain management approval for new spiral curriculum, to share with External Examiner, and to update IChemE UK on the changes made. To explore obtaining additional external validation of the revised curriculum, in relation to meeting E&C SF requirements.			

Why Spiral Curriculum and How to Design One?

Spiral curriculum had been implemented in several chemical engineering programs, for example, see DiBiasio, et al (1999), Gomes et al (2006). This curriculum model is adopted because we believe it is best able to deliver the outcome desired from the redesign effort in good alignment with the E&C SF: a course structure that can accommodate the learning needs of both adult learners and students. The general approach we had taken in transitioning the existing curriculum into a spiral one is shown schematically in Figure 1. Note that the changes are made only to selected core modules, i.e. those directly mapped to the TSCs of the E&C SF. The colour rectangles on the left represent existing core modules in DCHE, while the white rectangles on the right represent the new curriculum, based on the concept of modular certificates (MCs). Each MC represents a collection of related modules, usually based on a set of core competencies. MC1 for example, consists of 3 modules MC1-1, MC1-2 and MC1-3. The MCs are arranged ("stacked") in a sequence of learning progression with increasing difficulty from MC 1 to MC5. MC6 is unique in the sense that it represents a single Enhanced Internship that students undertake, as briefly explained earlier.

Each module in the MC system is derived by combining related topics from existing modules (i.e. the colour rectangles). An example of this is shown in Figure 2, whereby an existing Year 2 Core Module 3 is firstly decomposed into its various topics represented by small squares. Similar approach is taken for other existing core modules. Squares of similar nature, but from different modules are then combined to form a new module in the MC system. This is best illustrated with an example from DCHE using a Year 2 core module entitled *Heat Transfer and Equipment*. In the existing structure, the module covered the all topics related to heat transfer: such as fundamentals, mechanisms, types of equipment, design and sizing calculations, modelling and simulation, operation and troubleshooting. Likewise, another core module entitled *Rotating Equipment* similarly covered all topics related to rotating equipment. For the new course structure, all topics from existing core modules related to, say design and sizing calculations, will be grouped under a new module in the MC.

Also shown on the right-most side of Figure 1, are labels such as E&C SF TSC L2, L3, etc. These represent the proficiency levels, based on the E&C SF, to be progressively developed over the 3-year duration of study.

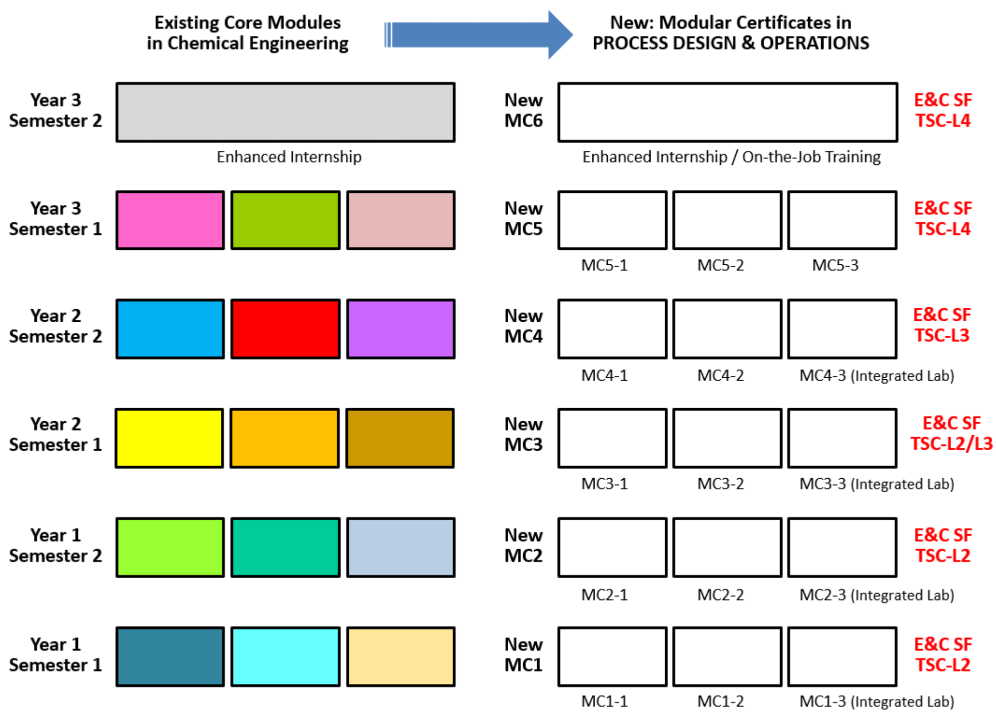


Figure 1. Modules in Existing Course Structure (left – coloured boxes) and New Modules in Proposed Spiral Curriculum Course Structure (right – white boxes)

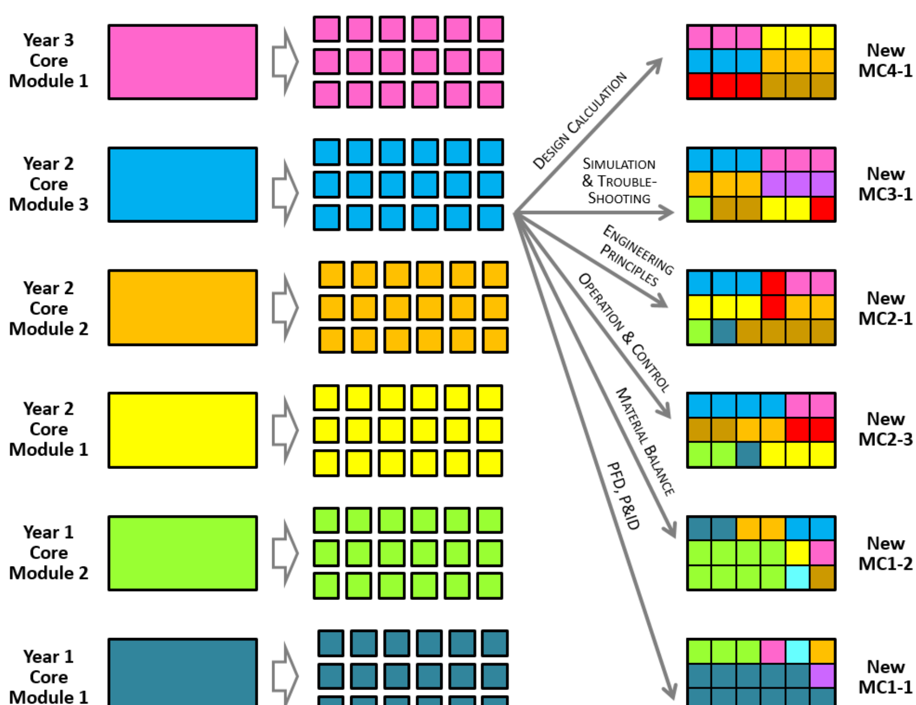


Figure 2. Approach to Redistribution of Topics in Existing Modules to New Modules

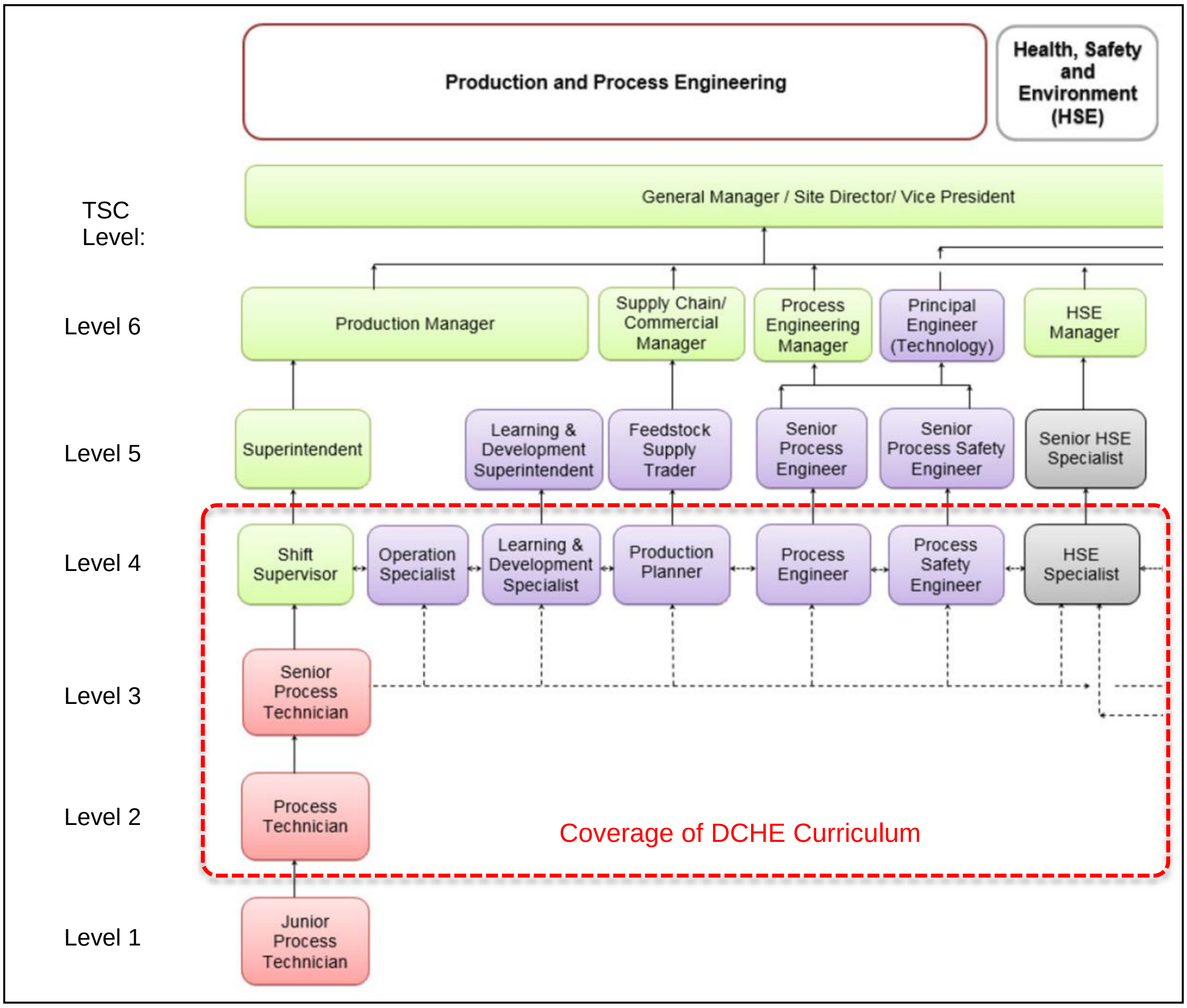
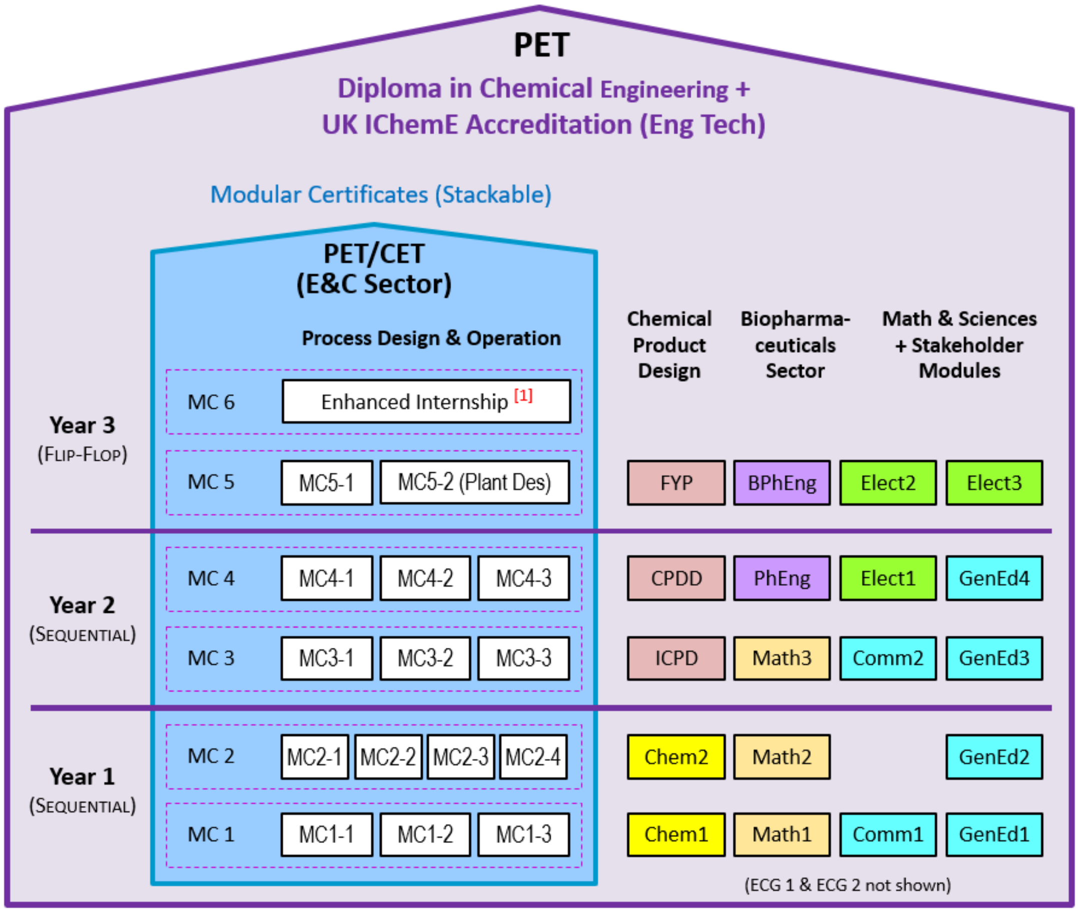


Figure 3. Partial Career Map for Energy & Chemicals Sector

These levels broadly correspond to the Job Roles and possible career pathways in the E&C industry. A partial career map for the E&C sector is shown in Figure 3, with 2 of several tracks in the E&C Industry, namely Production and Process Engineering; and Health, Safety & Environment (HSE). Also shown in Figure 3 is the focus of our curriculum design, where we attempt to map the new modules in the spiral curriculum according to the needs of a person to progress vertically from Process Technician up to Shift Supervisor; and from there horizontally to various positions such as Operation Specialist and Process Engineer to Process Safety Engineer and HSE Specialist.

The revised course structure is shown in Figure 4 as "House within a House". With this we would be able to accommodate the learning needs of both adult learners and students under the SkillsFuture Initiative. Full-time (PET) students will take the full suite of modules covered by the big house, whereas adult (CET) learners can choose to pursue one or more MCs within the small house, depending on their career upgrading requirements, as shown earlier in Figure 3. The model also allows the "blurring" between PET and CET where adult learners may join the full-time students in classroom learning in so far as the MC-based modules are concerned.



Note [1]: For CET, this will be replaced with Company OJT

Figure 4. Revised Spiral Curriculum for DCHE

To provide a focal point of all core modules in the re-design effort, a typical chemical process plant is chosen to serve as "anchor" upon which the teaching of all chemical engineering related topics will make reference to the chosen chemical plant. This is to provide a consistent "sign post" in an integrated curriculum when building up the students' technical know-how from MC 1 all the way to MC 5 in a progressive manner. The typical chemical plant must be one that is commonly used in the chemical industry, utilises most of the unit operations needed in the DCHE curriculum, and technologically not too complicated.

All lecturers in DCHE are now in the midst of redesigning their respective modules in line with the abovementioned approach. The target roll-out date for the new spiral curriculum is April 2018. To meet the aggressive timeline, a series of meetings were planned, where the concept of spiral curriculum was explained, doubts clarified and the approach presented. Every Wednesdays were blocked for all lecturers to get together to discuss how best to "slice up" his/her respective module and reconstitute the components into a new module in the stated MC. The Year Coordinators (3 of them, one for each year of study) within the Course Management Team (CMT) takes the lead to guide the development work, supported by the Course Chair and Academic Mentors. Each year coordinator will mobilise the module coordinators and the team members on an as-needed basis to work on new modules under each MC.

Since every lecturer is a module coordinator of one or more modules, and at the same time a team member of other modules, such an approach ensures that each lecturer is made aware of the development work undertaken by everyone else. A master Excel file was created using Google Sheets so that at the end of each meeting, every module coordinator can enter the changes to be made, which can be referenced by everyone else. The Year Coordinator focused on the technical details of each module, especially the inclusion of all necessary content (i.e. the small coloured boxes in Figure 2); while the Course Chair assisted by the Academic Mentor reviewed the proposed new modules and ensure that the required integration and progressive learning are in place. Where omissions or shortfalls are detected, the Academic Mentor work with each module coordinator directly to improve the design of the said module.

At the time of this writing, all Year 1 modules (MC1-1, MC1-2, MC1-3, MC2-1, MC2-2. MC2-3 and MC2-4) are within different stages of receiving approval from the school management to implement the changes made.

CONCLUSION

This paper presented the journey undertaken by the Diploma in Chemical Engineering to re-design its curriculum after 10 years of implementing CDIO. The outcome showed that the CDIO Framework remained useful and relevant to guide the re-design process to handle the challenges posed by Chemicals 4.0. The self-evaluation process using the CDIO Standards proved most useful in guiding the team in the staged development of technical skills and competencies and generic skills and competencies as detailed in the Energy and Chemicals Skills Framework using the spiral curriculum approach.

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BIOGRAPHICAL INFORMATION

Sin-Moh Cheah is the Senior Academic Mentor in the School of Chemical and Life Sciences, Singapore Polytechnic; as well as the Head of the school's Teaching & Learning Unit. He spearheads the adoption of CDIO in the Diploma in Chemical Engineering curriculum. His academic interests include curriculum revamp, academic coaching and mentoring, and using ICT in education.

Katerina Yang is the Course Chair for the Diploma in Chemical Engineering, School of Chemical and Life Sciences, Singapore Polytechnic. She leads the curriculum review for the diploma program to adopt the spiral curriculum model.

Corresponding author

Mr. Sin-Moh Cheah
School of Chemical & Life Sciences,
Singapore Polytechnic
500 Dover Road, Singapore 139651
smcheah@sp.edu.sg

5

TRAINING THE STAFF – HOW TO DEVELOP PERSONAL AND INTERPERSONAL COMPETENCIES AT FACULTY LEVEL

Jane Flarup

Associate Professor, MA, GDBA, Head of the Business Engineering Studies, Department of Business Development and Technology (BTECH), Aarhus BSS, Aarhus University.

Helle Wivel

Associate Professor, M.Sc.Mech.Eng., e-MBA, Head of the Mechanical Engineering Studies, Aarhus School of Engineering (ASE), Science and Technology, Aarhus University.

ABSTRACT

This paper aims to complement two previous papers by the authors (Flarup & Wivel, 2013; Flarup, Wivel & Munk, 2017) about how to design process enablers to strengthen project work at the mechanical engineering studies. Joining the CDIO Initiative in 2010, it has been the management's strategic focus at ASE to apply the rationale at all levels. Starting with the students, we recognized – as a surprising finding – that our work during the past years has increased the students' general well-being and, at the same time, dramatically reduced the dropout rate of the study program. We then realized that we needed to train the trainers to strengthen this positive process. The purpose of this paper is thus to illustrate how we work and intend to work with the staff, especially on the mechanical engineering studies, in order to fulfill the intention of the CDIO rationale. This article adopts the theory of self-efficacy, collective efficacy, and well-being (Bandura), as the supervisors and student tutorial supervisors are important as role models for the students in the project work. The conclusion is that the trainers are highly important as change agents at the faculty level and that an increased focus on staff training is very useful in this cultural change of mindset and practice to a CDIO rationale. The article is related to CDIO standard 9 – Enhancement of Faculty Competence.

KEYWORDS

Well-being, self-efficacy, role model, project work, process enablers, coaching, supervision, dropout, retention, mechanical engineering, personal and interpersonal competencies, faculty competencies, standard 9.

INTRODUCTION

The phrase "personal and interpersonal skills" is mentioned in six out of twelve CDIO standards, and in a seventh, the phrase "social learning" is used. The CDIO framework focuses strongly on a new engineering profile which includes a more holistic view on the professional engineer. For the future, we need to develop, in the words of Professor Edward Crawley (MIT), "whole, mature, and thoughtful individuals" (Crawley, 2001, op.cit. Flarup & Wivel, 2013, p. 7).

In 2013, we wrote our first article about process enablers for strengthening project work (Flarup & Wivel, 2013). In that connection, we realized that grades or exams was not the most important parameter for the quality of the project work. Instead, we found that the students' well-being and social competencies in the team's collaboration process were crucial for the quality of the report and the engineering solution and that this well-being was an influencing factor in a significant retention rate, especially at the 1st and 2nd semester. At that time, we did not know how fundamental this tendency was.

TACIT KNOWLEDGE

In the article, we concluded, "Personal and interpersonal skills are tacit knowledge, learned and performed by the student through social and professional relations" (Flarup & Wivel, 2013, p. 1).

The intention of this paper is to elucidate the following issues: how is this tacit knowledge transmitted to the students and by whom? How do the students learn tacit knowledge and how do they learn to behave and think as an engineer in order to be a full member of an engineering culture?

In the article, we describe activities that already take place and activities we intend to organize in order to implement the CDIO rationale at all levels. In short: how can tacit knowledge be explicated to the new students by older student colleagues, supervisors and teachers in the learning environment at the mechanical engineering study program? And how is this process of transmitting tacit knowledge attached to the staff's and the students' personal and interpersonal competencies?

The CDIO Syllabus

In the CDIO Syllabus (Crawley, 2001), we recognize that personal and interpersonal competencies are the basic skills for an engineer. The left side of the model below depicts professional skills with detailed descriptions, and the right side shows teamwork and communication, which are less defined and seem to derive from the professional skills.

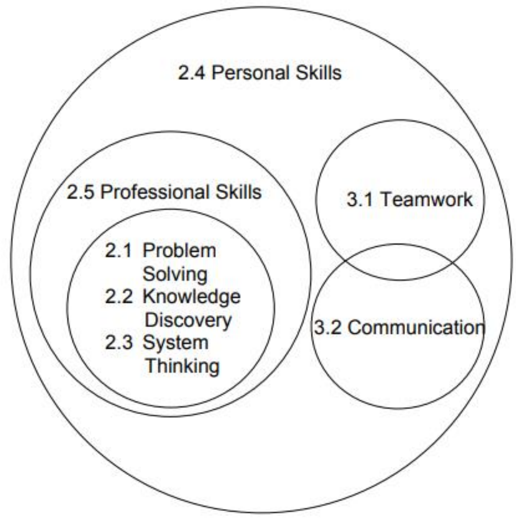

Figure 1: Venn diagram of the CDIO rationale (Crawley, 2001, p. 7).

As we mentioned in 2013 (p. 3), we found the description of personal and interpersonal competencies too vague:

> "[…] personal skills are an immanent competence for professional skills, teamwork skills and communication skills. But while the area of professional skills is well described in the model we assess that it is insufficient to define personal skills by just mentioning the other features. We think that the thinking underneath this model lacks specific terms of how to train the students' personal skills."

Over the years, the CDIO rationale has been extended with further specifications. In Crawley (2007), the model has been developed into the diagram below:

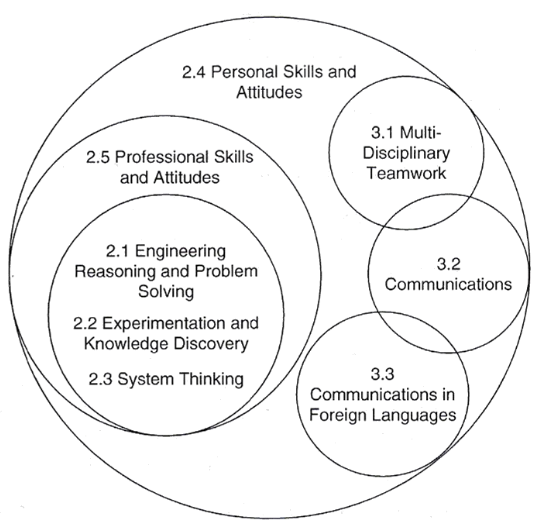

Figure 2: Venn diagram of the CDIO rationale (Crawley, 2007, p. 52).

Professor Crawley now defines personal skills and attitudes as social competencies in the learning environment, "*Interpersonal Skills* are a distinct subset of personal skills that divide into three overlapping subsets: *Multidisciplinary Teamwork* (3.1), *Communications* (3.2) and *Communications in Foreign Languages* (3.3)" (Crawley, 2007, p. 52).

In our second paper (Flarup et al., 2017), we demonstrate how we at the mechanical engineering study program since 2012 have trained students in these social skills by focusing on teamwork, communication, and project management. It is exactly by this combination of personal and interpersonal competencies that we see a dramatically reduced dropout rate on the first two semesters. The table below shows tools that stimulate the students' engineering skills and their psychological competencies. The tools and teaching are related to an overall approach to the student activities (from the beginning of their studies to their graduation) that is based on a human relations management four-phase framework (attraction, retention, development, dismissal/parting (Armstrong, 2008; Arthur, 1995).

	Tools	Processes	Teaching	HRM
1st semester	Psychometric test: Insights Discovery (see: www.insights.com). A work profile. Teams write a report to document the team work process.	Coaching of teams (two lessons per semester) according to the individual work profiles.	Introduction to Insights, including teaching in communication and perception (two lessons per semester).	Introduction to the engineering culture.
2nd semester	Conflict behavior test.	Coaching of teams (two lessons per semester). Focus on teamwork, project management tools, and conflict behavior.	Introduction to team theory, conflict theory, and collaboration theory (two lessons per semester).	Retention to the engineering culture and learning environment.
4th semester	Leadership test (e.g., Addize).	No coaching. If the team has problems, it is possible to ask for coaching (most often, the teams only need one extra coaching session (equal to two lessons)).	Introduction to organization theory, business life, professional behavior, and communication (two lessons).	Development of the individuals in the learning environment.
6th semester	In progress: the VIA character strengths – psychological test showing individual character strengths (see www.VIA.org).	Coaching in the use of tools if needed, e.g. project management tools, conflict management tools.	Introduction to career planning and individually organized project teams.	Adjourning phase.

Table 1: Tools for training the mechanical engineering students' personal and interpersonal competencies at ASE.

These activities are constantly refined in order to motivate all kinds of mechanical engineering students, despite their sometimes skeptical attitudes towards personal and social development, to participate more comprehensively. We conclude in the article, "we see an increase in the overall well-being of the students, and in general, they proactively tackle any collaboration issues of the teams and exhibit a higher motivation for engaging in social activities" (Flarup et al., 2017, p. 2).

SELF-EFFICACY

The concept of mastering a task is crucial for understanding our student and staff training program (Flarup et al., 2017). Based on Bandura's social cognitive theory of self-efficacy (1987, 1994), self-efficacy is the feeling of mastery.

There are four sources for developing personal self-efficacy:

1) An experience of being able to master life in general and a challenge in particular.

2) Influence from a role model – a teacher, a supervisor, a mentor, an older student, or someone you resemble and admire.

3) Influence from social persuasions, meaning that the role model or other sources of influence convinces you that you are able to master a situation or a challenge, for instance a study.

4) Positive emotions, meaning that the way you handle your feelings about your ability to master something is crucial for whether you are a success or a failure.

It is important to work with your positive and negative emotions about yourself, as these emotions are predictive for the result. Bad thinking makes things go bad, whereas positive thinking increases the chances of success (Baumeister et al., 2001). Training your positive emotional competencies makes you believe in yourself in any respect. The more you master your life in general and the more you believe in yourself, the higher the level of well-being and the stronger the feeling of inner motivation for performing well will be. Bandura's theory self-efficacy corresponds to the motivation theory of Deci and Ryan, which is also very important for understanding our activities. The motivation theory stresses that inner motivation is rooted in a person's feeling of autonomy and independence, but also a strong sense of kinship with other people and a feeling of mastery and competence (Deci & Ryan, 2000). This leads to the third basic element of our program: how to train the students' feeling of flow in team work. Flow is connected to a high feeling of individual and collective mastery and a high level of inner motivation (Csickszentmihalyi, 1989).

Based on research, we have earlier argued (Flarup et al., 2017) that university students who have high levels of general efficacy, positive emotions about themselves and high levels of well-being and inner motivation for studying have a much lower risk of dropping out of their studies – even in the face of overwhelming challenges – because general self-efficacy is linked to a greater sense of purpose in life. By contrast, students with lower general self-efficacy perceptions have a much higher risk of dropping out, even though they might get good grades in the exams or are very socially active in their study environment. The conclusion is that we train our students to achieve an improved sense of general self-efficacy, a positive attitude towards themselves and a general personal grit to resist challenges in the study and in their encounter with the engineering career and culture. The result is that the dropout rate of the mechanical engineering studies has fallen dramatically, especially on the first two semesters.

COLLECTIVE EFFICACY

For the mechanical engineering project student teams, it is very important to work with the team members' collective efficacy. Bandura (1987, p. 477) highlights that collective efficacy is based on the individual member's feeling of positive self-efficacy as described above. In order to enhance professional skills in project work, it is firstly important to train the individual to work together with other individuals in the team. Bandura defines collective efficacy as the team's perceived collective mastery of the project work, and this perception is more than the sum of the people and their competencies: it is the team's synergetic belief in itself. Other criteria for the well-functioning team are how well it is organized, how the team roles are distributed, and how well the team is run (management). The most influential factor for a high level of collective efficacy in a mechanical engineering team is an empathetic communication style that encourages the members to commit to the work by drawing on their inner motivational resources as described theoretically above. Bad communication creates conflicts and demotivates the team members.

The team members' sense of doing well is crucial for the quality of the project work, and it is the fundamental issue when we design activities to enhance professional skills. The psychometric test profile, process reports, and team coaching are tools that are basically introduced at the mechanical engineering studies in order to train individual and collective efficacy. All teachers are offered an education in the psychometric test system, which is, as mentioned above, the basic tool in our understanding of good communication in team work. This leads to the question: how to train the trainers as role models in Bandura's understanding in order to fulfill the above-mentioned activities?

ROLE MODELS, MASTERY, AND PEER TRAINING

In mastering a task, the influence of a role model is very important. Since introducing the tools at the mechanical engineering studies, we have designed a program for the first two semesters that includes a central role model: a team coach. On the first semester, we have chosen a mechanical engineer (female), and on the second semester, there is a team coach who has a background in Human Relations Management and project management experience from the business life. The coaches have not been chosen randomly, as both are expected to instill trust in the students: for the new students a mechanical engineering coach is exactly what they need in order to feel safe in the new environment, imparting them with a sense of 'if she can do it, I can too'. On the second semester, the students feel more included in the engineering culture and focus on an engineering career. For this, we have chosen an HRM-trained coach, but it could be any kind of coach, depending on the issues we want to the coaching sessions to train.

Our next step in introducing the students to the engineering culture is to train the trainers to acquire a deeper understanding of the role they play in the students' success. The trainers are at several levels, as illustrated in the table below:

Trainer	Task	Tools
Teachers	Classroom teaching.	Cases, dialog based on teaching, lab work, peer discussions, exercises, tasks, e-learning. These teachers are professional role models.
Supervisors	Supervising project work in teams.	Engineering subjects, revising projects. The supervisor is a professional role model.
Three student tutorial supervisors per course – three lessons per tutor per week.	Individual training: teaching exercises, demonstrating engineering tools, helping with professional issues.	In class. Revising tasks and teaching subjects from the curriculum. The older students are peer role models.

Table 2: Three levels of trainers – teachers, supervisors and student tutorial supervisors, and their tasks and tools.

All staff at ASE is educated in the Insights Discovery work preference test tool, which ensures that there is a common language to understand colleagues and students. In addition, we intend to organize an onboarding team at the mechanical engineering studies for the new teachers and supervisors in order to introduce them to the learning environment and the CDIO rationale. This onboarding team could focus on three issues:

- Personal and interpersonal competencies: how and why we use the Insights Discovery preference test tool, how and why we teach in personal skills, and the relationship to the CDIO syllabus.
- Professional competencies: how we supervise project work in this learning environment related to the CDIO rationale.
- Strategic and organizational competencies: how and why we seek to strengthen supervising methods and teaching and the general relationship to the CDIO rationale.

The onboarding team also has the opportunity to invite new colleagues to attend the coaching and supervising sessions, and the new colleagues are free to invite experienced colleagues to observe their coaching and supervising project work in order to receive valuable peer feedback and to create more standardized supervision methods. One of our colleagues has filmed his project planning and work process in order to exchange ideas with his colleagues and to strengthen and standardize a supervision method at the mechanical engineering studies.

TEACHING – CONSULTING – SUPERVISION – INTERVISION

The organizational culture at ASE is generally hallmarked by a close relationship between students and teachers. Even though we have classes of 100 or more students, the culture is characterized by a flat organizational structure and an open and informal communication style, which is a significant trait of the Scandinavian culture (Hofstede, 1993). For us, teaching, supervising, tutoring, and discussing are seen as ways of coaching (Loew, 2009,

p. 39), and by doing so, coaching is represented in the following model as several steps in the space between giving answers and asking questions depending on the situation:

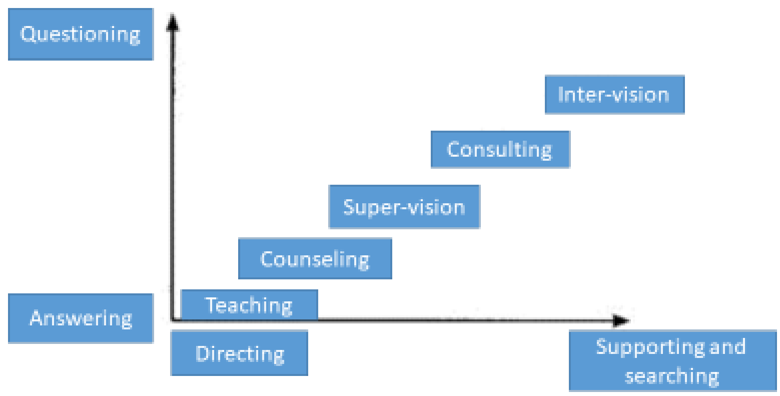

Figure 3: The teaching, counseling, supervision, consulting, and inter vision positions in project work. Team coaching can be viewed as a more consulting or inter visionary way of teaching (Loew, 2009, our adaptation and translation).

The scale demonstrates several positions for the teacher in the classroom and the supervisor in the project work. Teaching in the classroom will take a more directing and instructive position in contrast to supervision of a project work (super in Latin means 'over'), which includes a more searching position in interaction with the students. Supervision or guidance of project work will assume a more counseling form, whereas team coaching includes a more personal and interpersonal supportive attitude that relies on a mutual, equal, and inter-visionary (inter in Latin means 'between') position, as the students are experts on their own lives and the coaching sessions aim to elicit the teams' strengths and weaknesses (Cooperrider et al, 2008; Kauffman, 2006).

Student tutorial supervisors are seen as possible coaches for the new students, and we intend to do more training of older students in personal and interpersonal skills as a part of the onboarding team activities. This student tutorial activity will be organized as six months of supervision of the tutors, after which they will receive a diploma with details about the content of this training in professional teaching, supervising, and coaching in personal and interpersonal competencies.

This leads to a discussion of the symmetric and asymmetric roles in the relationship between students and teachers, supervisors and tutors. In other words: why can't teachers be personal and interpersonal coaches for the student teams?

ASYMMETRIC AND SYMMETRIC RELATIONSHIPS

In general, the mechanical engineering students increasingly expect their teachers to change their attitude and supervise in the language of the psychometric personal work profile. The students prefer supervisors who demonstrate empathetic competencies and are willing to enter into a more supportive and personal relationship with the teams. Research has shown that the better the relationship between supervisor and teacher, the higher the quality of the students' learning (Hattie & Yates, 2014).

On the other hand, research in leadership and coaching shows that an equal relationship between employee and coach (in this case, student and teacher) is problematic because of power imbalances (Hersey & Blanchard, 1982). The question is: will the students open up about personal and interpersonal issues to the coach when he or she is the one who evaluates the team and gives grades?

Another challenge is the roles of the teacher as supervisor and coach in project work counseling. This dual role can destabilize his or her role as an expert, because coaching includes questions and a mutual relationship in contrast to the supervising role, which is based on professional expertise and the act of giving answers.

Research about coaching in leadership and the asymmetric relationship is well-known. The famous model of Hersey and Blanchard demonstrates that the manager and leader can use different styles in managing the staff according to the person's maturity (a combination of motivation and competencies). The model is shown below:

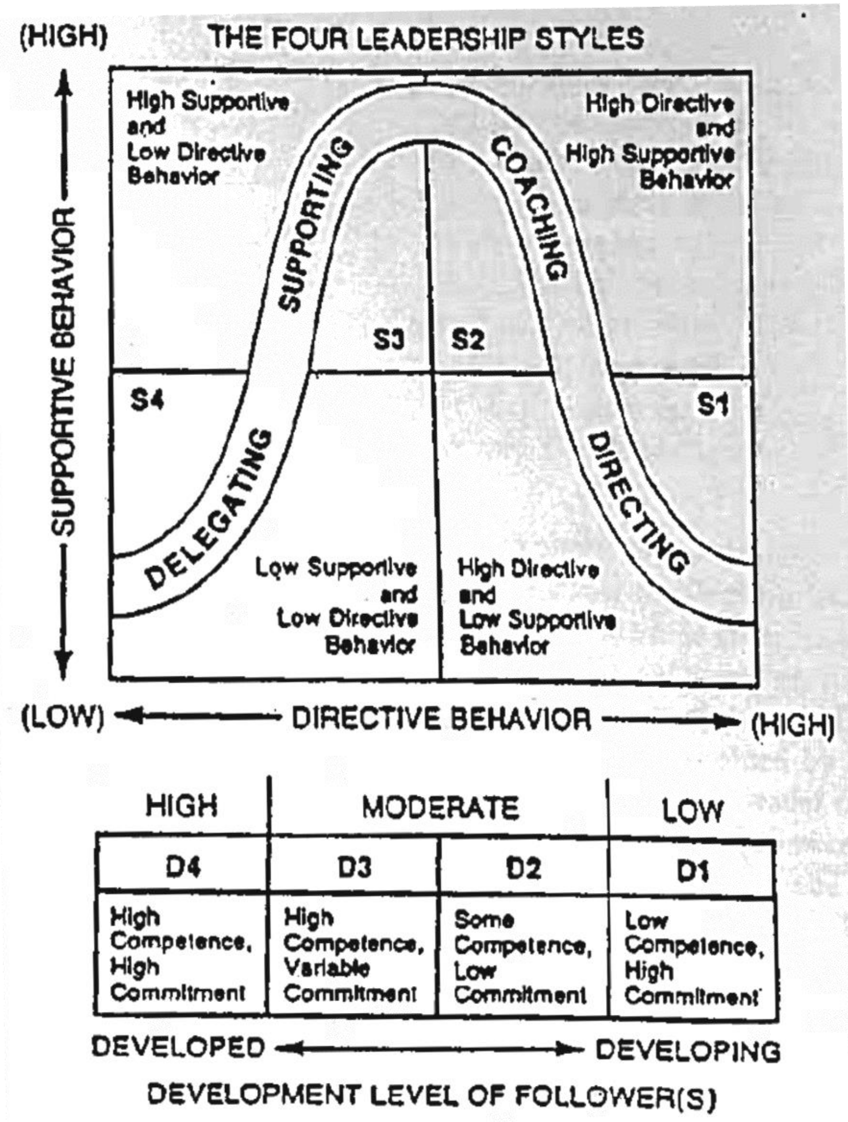

Figure 4: Hersey and Blanchard (1982): situational leadership.

The model illustrates that a coaching leadership style (S2) refers to an employee (in this case, the student) with some experience and low commitment. A teacher in the classroom has a more directive attitude, which refers to the first style (S1). The dynamic of the model is that the leader (in this case, the teacher or supervisor) develops the person's professional skills by a combination of directive and supportive behavior to a high competence level and a high commitment level.

This leads us to conclude that training the teacher and supervisor to use coaching tools (a questioning style) on professional topics will stimulate the students' feeling of motivation, mastery, and positive emotions about their competencies. Whereas coaching in personal and interpersonal issues has to be reserved for a neutral person, for instance an older student or an external coach.

To sum up, we train the trainers as change agents on several levels:

Onboarding team	New colleagues – training program.
Exchange forum	Discussion forum for the staff about professional (and interpersonal) topics.
Insights Discovery preference profile	All staff is tested, some are educated in using the test tool. A common supportive language for the mechanical engineering studies.
Supervision of older students	Junior colleagues – training in personal, interpersonal, and professional issues.

Table 3: Train the trainer activities at the mechanical engineering studies. Trainers as cultural change agents in the mechanical engineering environment.

CONCLUDING REMARKS – ARE WE ENCOUNTERING A NEW CULTURE?

As we have demonstrated above and in our former papers (Flarup & Wivel, 2013; Flarup et al., 2017), the psychometric work profile test tool, the team coaching sessions, including tools and models, and the process report indicate that the level of self-reflection on part of the student teams as to their personal and interpersonal development is very high. This corresponds to the self-efficacy theory, which defines well-being as a feeling of mastering the situation professionally and personally. The theory shows that the guidance of a trustworthy role model aiming to strengthen efficacy is necessary for students to improve their positive view on their skills and motivate them for the work. Albert Bandura, the father of the theory of self-efficacy, points out that strengthening learning environments in order to train the students' ability to feel mastery and personal emotions is of crucial importance for the students in enduring challenges in the study environment and in their future careers as mechanical engineers. For the teams, the feeling of synergetic and collective efficacy is key to deliver high-quality project reports of importance for the society.

This is exactly the purpose of widespread activities at the mechanical engineering studies, beginning with the team coaching sessions headed by an engineer on the 1st semester, an HRM coach on the 2nd semester, student tutorial supervisors assigned to all courses, and finally, the teachers functioning as supervisors of the project work and in the classroom teaching. All are role models for the students, and by their common language as engineers and in respect of the issues of personal and interpersonal skills (e.g., by using the Insights Discovery preference tool), the new students are included in the modern engineering culture as "whole, mature, and thoughtful individuals" (Crawley, op. cit.; Flarup & Wivel, 2013, p. 7). The HRM four-phase framework outlines a general understanding of the path into the culture for every single student as well as the milestones for the staff and teachers. By that, we have noticed a dramatically reduced dropout rate on the first two semesters, and we hope that the coming activities will reduce the dropout rate for the later semesters as well.

The Head of the Mechanical Engineering Study program observes a new engineering culture at ASE, which has developed since the introduction of the CDIO rationale. This emerging culture includes both the students and the faculty competencies as change agents, which the CDIO framework aims at. She summarizes:

"Slowly, a new culture has emerged. It is different than six years ago. The students are met at eye level; we see them, we listen to them, and we try to understand them. They have become much more open – it is ok for them to say that something isn't working and that their feelings matter. They are better equipped at handling social anxiety, and they have great empathy for each other. Their behavior seems more personally and professionally competent."

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BIOGRAPHICAL INFORMATION

Jane Flarup, MA, GDBA (jfl@btech.au.dk). She is an Associate Professor and the Head of the Business Engineering Studies at Aarhus University, Denmark. She holds a Master of Arts and Communication, a Master of Positive Psychology (MoPP, exp. June 2018), and a GDBA. She is a member of the MBIT research group at the Department of Business Development and Technology, Aarhus University. Together with Helle Wivel, she is the author of a CDIO conference paper (2013), and together with Helle Wivel and Christina Munk, she is the author of a CDIO conference paper (2017). She continues to conduct research on this topic together with Helle Wivel. She is team coach and coordinator of the personal and interpersonal activities at the Aarhus School of Engineering.

Helle Wivel is an Associate Professor, M.Sc.Mech.Eng (hwi@ase.au.dk). She holds a Master of Mechanical Engineering and an e-MBA, and is the Head of the Mechanical Engineering Studies at Aarhus University, Denmark. Together with Jane Flarup, she is the author of a CDIO conference paper (2013), and together with Jane Flarup and Christina Munk, she is the author of a CDIO conference paper (2017). She continues to conduct research on this topic together with Jane Flarup.

Corresponding authors

Associate Professor, Head of Business Engineering Studies
Jane Flarup
Aarhus School of Engineering, ASE
10, Inge Lehmannsgade
8000 Aarhus C
Denmark
jfl@btech.au.dk

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CDIO-BASED CURRICULUM DEVELOPMENT FOR NON-ENGINEERING PROGRAMS AT MASS COMMUNICATION TECHNOLOGY FACULTY

Uravis Tangkijviwat, Wanchanok Sunthorn, Natchaphak Meeusah

Faculty of Mass Communication Technology,
Rajamangala University of Technology Thanyaburi

Natha Kuptasthien

Faculty of Engineering, Rajamangala University of Technology Thanyaburi

ABSTRACT

Faculty of Mass Communication Technology (MCT) at Rajamangala University of Technology Thanyaburi (RMUTT) has adopted CDIO framework as a context for producing professional hands-on graduates since 2015. MCT faculty has adopted CDIO framework in curriculum development for all six programs; namely, Multimedia, Digital Media, Television and Radio, Photography and Cinematography, Advertisement and Public Relations, and Digital Printing and Packaging Technology. Curriculum development process consisted of (1) a stakeholder survey focusing on future of the world of professional work (2) an implementation of CDIO standard 2 to identify program outcome and graduate attributes and (3) an implementation of CDIO standard 3 for integrated curriculum. The introductory course for each program was introduced to the first year students. With a support from the university, a major renovation of workspace and laboratories was undertaken. The state of the art workspaces supporting students' learning experiences are studio, theatre, render farm lab, 7.1 sound studio, stop motion studio, printing house, TV master control room, and fabrication laboratory. This paper showed similarities and differences of six programs when implementing CDIO concept. Program self-assessment regarding CDIO 12 standards revealed a high commitment to continuous improvement for quality of education.

KEYWORDS

Curriculum development, non-engineering programs, CDIO standards: 1-12

INTRODUCTION

Mass media is one of the most useful essences of human life. There are a variety of mediums from which people can pick and access information from press, radio, television and film. It educates people about the world outside of their locate boundaries and also acts as an important accountability mechanism by acting as a watchdog of society. Consequently, the media holds a very powerful capacity to set a social issue. In the recent years, the mass media industry is undergoing significant change, with digital distribution platforms joining traditional media. New era media, for instance internet and social media, has evolved over the last decade and became an important driver for acquiring and spreading information in different aspects, such as entertainment (Shen et al., 2016), business (Stefan et al., 2018 and Hatem et al., 2018), and so on. In an aspect of academic, most of education in mass communication is devoted to social science and art domains. These programs approach to a message design regarding sender and receiver behaviors. In a differential domain, the programs in the faculty of Mass Communication Technology (MCT), Rajamangala University of Technology Thanyaburi (RMUTT), are integrated with science, technology, and design. The graduates were expected to possess various skills to develop instruments and techniques for making mass medium that meet stakeholders' requirements

The CDIO framework was first adopted in mechanical and aerospace engineering. The improvement of several programs based on Conceive – Design – Implement – Operate, hence, has been widely implemented in the field of an engineering education (Crawley et al., 2007). However, CDIO is not limited to application in engineering programs. It is also applied to non-engineering programs. Doan et al. (2014) proposed the generalized CDIO standards for other disciplines to make them more applicable to any program. Malmqvist (2015), furthermore, revealed a practical experience of how to translate CDIO standards to non-engineering contexts. Although the guidance for implementation of CDIO in non-engineering programs was explored (Malmqvist at al., 2016 and Hladik at al., 2017), there is a lack of an application for mass communication. This paper, therefore, aims to address this gap in the field of mass media.

This study illustrates the way to apply CDIO in the field of mass communication and how to improve students' performance. First, we describe the implementation and experiences of non-engineering CDIO programs. The next section exposes case studies in the subjects of principles of media production for multimedia and light and sound technology for stage. Finally, the paper is concluded.

THE CDIO APPROACH

The program outcome for MCT is to produce the hands-on professional graduates who meet the industrial and social requirements. CDIO framework shows high committed results for enhancing a quality of mass communication education. As stated in CDIO context (CDIO standard 1), the CDIO principle was presented and promoted to all faculty members in the annual seminar in 2014. One year later, six curriculums of undergraduate programs; namely, Multimedia (MM), Digital Media (DM), Television and Radio Broadcasting (TR), Photography and Cinematography (PC), Advertisement and Public Relations (AP), and Digital Printing and Packaging Technologies (PT), were developed based on CDIO framework. Due to faculty's policy, conceiving, designing, implementing, and operating in terms of media and production lifecycle development are aligned in the senior project and subjects that carry out a mass media production. The students learn to solve problems and complete their projects following the stages of CDIO. Furthermore, the CDIO framework is appointed as a one of key performance indicators of faculty, such as increasing the faculties who have a CDIO advanced experience and stakeholders' satisfaction on working space.

For curriculum development regarding CDIO Standard 2, CDIO syllabus v.2.0 was used as a guideline. The stakeholder survey was conducted to acquire CDIO knowledge and skills proper to MCT context. The learning outcomes from mass media industries and fourth-year students who have experiences in cooperative education were shown in Table 1. In each section of CDIO syllabus, top three of desired learning outcome were showed as first, second, and third ranking, respectively. The overall result was a general response from all stakeholders rather than in particular programs. In the section of disciplinary knowledge and reasoning (section#1), the overall response showed that mass media industries concern the fundamental (CDIO syllabus 1.2), advanced (1.3), and mathematics and sciences knowledge (1.1), respectively. The same result occurred in the student point of view. It is noted that the skills of mathematics and sciences (1.1) is secondarily needed in the industries of DM, TR, and PC. In the section of personal and professional skills and attributes (section#2), the result is not unanimous. We found a different requirement among the programs and also between industrial and student aspects. However, a skill of experimentation, investigation and knowledge discovery (2.2) is founded as the smallest requirement. There is clearly a result in the section of interpersonal skill (section#3). The consensus is as followings: teamwork (3.1), communication (3.2), and foreign languages (3.3). Last but not least, in the section#4 the skills of conceiving and working system (4.3), implementing (4.5), and designing (4.4) are required in general, but there are different in the detail. For instance, a leadership skill (4.7) is exposed in DM, PC, and AP programs and an enterprise and business context (4.2) is occurred in PT program. In sequentially, the obtained CDIO skills are integrated into each curriculum to ensure that a qualification of graduates will meet to industry expectation (CDIO standard 3).

Table 1. Desired CDIO knowledge and skills set of six programs responded by stakeholders

<table>
<tr><th rowspan="2"></th><th rowspan="2">Programs</th><th colspan="3">Industrial aspect</th><th colspan="3">4th year student aspect</th></tr>
<tr><th>1st Rank</th><th>2nd Rank</th><th>3rd Rank</th><th>1st Rank</th><th>2nd</th><th>3rd Rank</th></tr>
<tr><td rowspan="7">Section #1</td><td>Overall</td><td>1.2</td><td>1.3</td><td>1.1</td><td>1.2</td><td>1.3</td><td>1.1</td></tr>
<tr><td>MM</td><td rowspan="6">1.2</td><td>1.3</td><td>1.1</td><td rowspan="6">1.2</td><td rowspan="6">1.3</td><td rowspan="6">1.1</td></tr>
<tr><td>DM</td><td>1.1</td><td>1.3</td></tr>
<tr><td>TR</td><td colspan="2">1.1 and 1.3</td></tr>
<tr><td>PC</td><td>1.1</td><td>1.3</td></tr>
<tr><td>AP</td><td rowspan="2">1.3</td><td rowspan="2">1.1</td></tr>
<tr><td>PT</td></tr>
<tr><td rowspan="7">Section #2</td><td>Overall</td><td>2.3</td><td>2.4</td><td>2.5</td><td>2.1</td><td>2.3</td><td>2.5</td></tr>
<tr><td>MM</td><td>2.4</td><td>2.3</td><td>2.1</td><td>2.1</td><td>2.3</td><td>2.5</td></tr>
<tr><td>DM</td><td>2.3</td><td>2.4</td><td>2.5</td><td colspan="2">2.1 and 2.5</td><td>2.3</td></tr>
<tr><td>TR</td><td colspan="2">2.1 and 2.5</td><td>2.3</td><td rowspan="3">2.1</td><td>2.3</td><td>2.5</td></tr>
<tr><td>PC</td><td>2.3</td><td>2.4</td><td>2.1</td><td rowspan="2">2.5</td><td>2.4</td></tr>
<tr><td>AP</td><td>2.4</td><td colspan="2">2.3 and 2.5</td><td>2.3</td></tr>
<tr><td>PT</td><td>2.3</td><td>2.5</td><td>2.4</td><td>2.3</td><td>2.1</td><td>2.5</td></tr>
<tr><td rowspan="7">Section #3</td><td>Overall</td><td>3.1</td><td>3.2</td><td>3.3</td><td>3.1</td><td>3.2</td><td>3.3</td></tr>
<tr><td>MM</td><td rowspan="6">3.1</td><td rowspan="6">3.2</td><td rowspan="6">3.3</td><td rowspan="6">3.1</td><td rowspan="6">3.2</td><td rowspan="6">3.3</td></tr>
<tr><td>DM</td></tr>
<tr><td>TR</td></tr>
<tr><td>PC</td></tr>
<tr><td>AP</td></tr>
<tr><td>PT</td></tr>
<tr><td rowspan="7">Section #4</td><td>Overall</td><td>4.3</td><td>4.5</td><td>4.4</td><td>4.3</td><td>4.5</td><td>4.4</td></tr>
<tr><td>MM</td><td>4.3</td><td>4.5</td><td>4.4</td><td rowspan="6">4.3</td><td rowspan="4">4.5</td><td rowspan="2">4.4</td></tr>
<tr><td>DM</td><td>4.5</td><td>4.7</td><td>4.3</td></tr>
<tr><td>TR</td><td>4.6</td><td colspan="2">4.3 and 4.5</td><td>4.1</td></tr>
<tr><td>PC</td><td rowspan="3">4.3</td><td rowspan="2">4.7</td><td>4.5</td><td>4.4</td></tr>
<tr><td>AP</td><td>4.4</td><td>4.1</td><td>4.7</td></tr>
<tr><td>PT</td><td>4.5</td><td>4.2</td><td>4.7</td><td>4.5</td></tr>
</table>

For introducing a basic knowledge in mass communication (CDIO standard 4), the subjects in principles of media production and mass communication technology are adopted as profession's context of practice in the first-year class to expose a scenery of industry. These subjects involve a media and system lifecycle development, consisting of theory and principles, methodology, tools and instruments, production process, project management, and factors that affect to medium. The conceive – design – implement – operate experiences are demonstrated in these classes. In the conceive stage, students learn how to fulfil the receiver or customer needs and expectations, what proper tools and techniques are, what environmental factors affect to, and how to solve the problems with the suitable solution. Planning, drawings, script writing, story boarding, and so on are proposed in the stage of pre-production stage (Design). In the implement stage, students transform their designs into products. Finally, the products are delivered to customers in the real working world in the operate stage.

For enhancing an experience of design and build (CDIO standard 5), furthermore, students are experienced with basic and advanced media production course and senior project. MCT has invested in setting up and renovating learning and workspace. These state-of-the-art laboratories are photography and cinematography studios, theatre, render farm lab (media server), 7.1 sound system studio, stop motion studio, printing house, TV master control room, and fabrication laboratory (CDIO standard 6). Examples of laboratories are shown in Figure 1.

All MCT programs offer a Cooperative Education which exposes students with work integrated learning experience (CDIO standard 7). Students spend at least one semester working at a company. They have a chance to integrate their knowledge and skill to the real-life situation. To improve teaching and learning, faculty members are encouraged to apply active experiential learning (CDIO standard 8). Learning assessment uses a variety of methods matched appropriately to learning outcomes (CDIO standard 11). With the aim to promote a community of practice, RMUTT provides a number of professional development training courses. Faculty members have been working in the industries which enhance the faculty competence (CDIO standard 9). To boost teaching competence (CDIO standard 10), faculty members must attend at least one training course per year. MCT has a long-term plan to offer a CDIO-related training course annually for a continuous improvement.

Figure 1. (left) Example of workspace: the photography studio
and (right) the TV master control room

CDIO PROGRAM EVALUATION

In order to track the continuous improvement of CDIO implementation, program self-evaluation using 5-score rubrics were conducted by the faculty members. The result was shown in Figure 2. Within each program, each bar represents the CDIO standard from standard 1 to standard 12, respectively. The result showed that some CDIO standards reached the maximum score, for instance CDIO standard 6 workspace for MM, AP, and PT programs, and CDIO standard 9 enhancement of faculty competence in DM and TR programs. However, a lower score was found in the program of PC with CDIO standard 1, 2, 3, and 6. The management, then, can use this program evaluation to plan for improvement further.

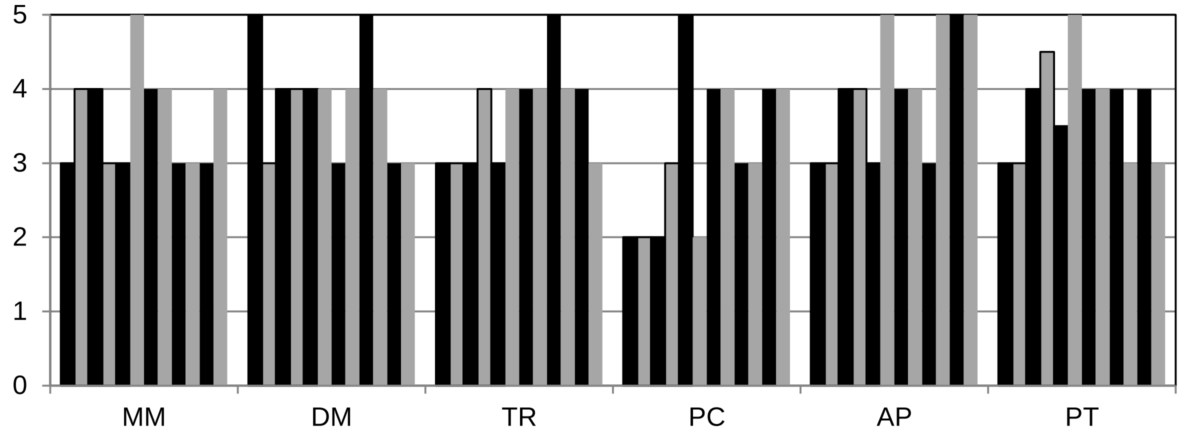

Figure 2. The result of CDIO program self evaluation

CASE STUDIES

The example of the subject that applied CDIO as a teaching technique are principle of media production for multimedia in the MM course and light and sound technology for stage in the DM course. The CDIO context applied in the projects was exploded.

Principles of Media Production for Multimedia

Background of the subject: In this subject, students will achieve a basic knowledge of media planning and production as well as financial management. There are several medium the student should be familiar with, for example, website, print media, animation and advertising media. The student reflection revealed that they found the course unattractive and boring. They are not satisfied with the outcome. Therefore, the instructor has reconstructed the applying the CDIO concept and a number of active learning activities.

Conceive: In the class, a variety of teaching and learning methods are applied, for example think-pair-share, brainstorming, problem-based learning, role-play, step by step and discussion. We found that the most powerful method is an instructional model of cooperative learning. This method is applied with a cooperative project in the last part of the course. As a cooperative project, a team of students is given a role as a design company. They are required to set up the company with employees in some job positions such as a producer, a designer, a copywriter, a photographer, etc. Each group visits an assigned community to find out their needs to create a suitable media and packaging for products.

Design: After analyzing the customer requirement, the planning of media production is developed. It is composed of logo, labels, advertising media, product packaging, website, and financial management. Then, a proposal is presented to the customer for improving the design.

Implement: Each group of the student creates all media and packaging of products as following to the detail they obtained from the previous stage. They make a prototype or mocked-up to verify the customer’s needs. The evaluation includes a suitable production technology, time management and teamwork skills.

Operate: In this stage, students present their work to the community. Community members select the best work that is suitable to their community for actual production. Figure 3 shows a presentation and the packaging design for natural beauty products.

Feedback from Students and Community: The feedback from students is a positive reflection. The CDIO project based learning gives students a chance to a real working world. They learned not only a professional skill but also a social skill. On the other hand, a community reflects the positive response. A community and students were collaborated as university social engagement. Both feedback from community and students' reflection is used to improve this course for the next semester.

Figure 3. (left) Presentation of design proposal
and (right) the developing packaging for beauty products

Light and sound technology for stage

Background of the subject: Light and sound technology for stage course is a selective course for the third year student in Digital Media Technology. After taking this course, students should be able to create and manage lightning for stage shows and be able to work well as a team.

Conceive: At a starting point of the CDIO adoption, the DM program committee paid a visit to a number of companies in a light and sound industry. The information on industry expectations and the student competency were collected. They are technology usage, conceptual development, time and project management, proper equipments, and utilization of manpower. The information was used to design the course. This course focused in developing personal skills as well as technical skills. Students were grouped and assigned to organize a show. The students' learning experienced consisted of obtaining customer's needs, project planning, team-working, be creative, be able to work under pressure and capable of finish project as scheduled. For second semester in 2017, the students selected to run a fashion and wedding show events.

Design: With the customers' requirement information, students analysed the needs, plan the project time line and develop a prototype. A storyboard of stage performance and a script planning of light and sound were developed. Moreover, they identified proper equipment and assigned duties for their team members.

Implement: The students used a computer software to simulate the show according to their analysis. This simulation allowed students to see whether their show would turnout as planned as well as which hardware and manpower should be used. The simulation was presented to the customers to check if it accurately matched with their needs or any further modifications are needed.

Operate: As the implementation stage turned out successfully as planned, students would be able to determine equipment needed and allocate manpower to the jobs. In this operation stage, teamwork is very crucial as it involved high personal responsibility and strong commitment. Since students were assigned to different duties, they needed to contact different people and worked under pressure.

Feedback from Students and Customers: Students' feedback was positive, as the process illustrated the real-life working. The customers had high level of satisfaction. As a result of the project, some of the students were offered jobs at the company.

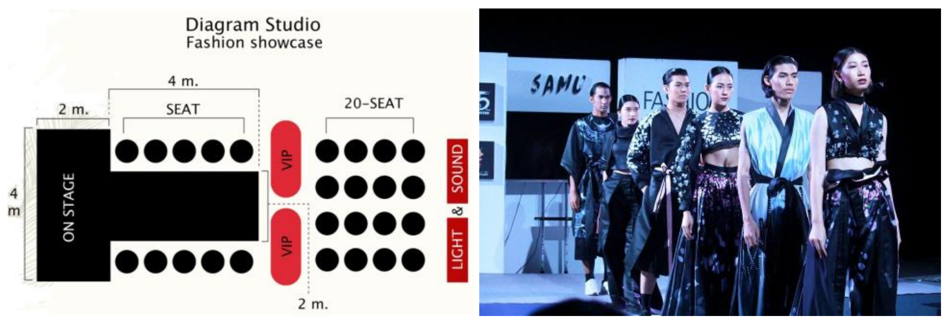

Figure 4. (left) Stage diagram for fashion show and (right) exposing on the catwalk

CONCLUSION

In this paper, we have shown that the CDIO approach can be applied to non-engineering program. The CDIO-base education can enhance the competency of graduates and faculty members that meet stakeholders' requirements. In general, we found the similarities in core competency of knowledge and skills among different programs in CDIO Syllabus 1.1, 1.2, 1.3, 3.1, 3.2, and 3.3. 12 CDIO standards can be used as a guideline how to implement into non-engineering program. Future work for MCT is to create a database for industry-related projects with CDIO concept for courses to cover all six programs. Therefore, the faculty member and student can benefit from experiential learning.

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BIOGRAPHICAL INFORMATION

Uravis Tangkijviwat received Master of Engineering and PhD in Integrated Science and Engineering from Ritsumeikan University, Japan and is currently as an assistant professor at the digital printing and packaging technology, faculty of Mass Communication Technology, RMUTT. His professional interests focus on colour science and human vision. As a deputy dean for academic and research affairs, he promoted the CDIO to faculty members and adopted the CDIO to undergraduate programs for enhancing the graduates in the field of mass media.

Natha Kuptasthien is currently as assistant to president for International Relations and an associate professor at the industrial engineering department, faculty of engineering, RMUTT. She has conducted a number of CDIO workshops at the faculty of Mass Communication Technology to promote CDIO with non-engineering programs. Natha graduated with a Bachelor of Engineering in Industrial Engineering from Chulalongkorn University, Master of Science and PhD in Engineering Management from University of Missouri-Rolla, USA.

Wanchanok Sunthorn received Master of Science in Technical Education and Bachelor of Science in Applied Mathematics from King Mongkut's University of Technology North Bangkok, Thailand. She has been teaching in Digital Media Technology programme in Faculty of Mass Communication Technology, RMUTT since 2011. In addition, she is a CDIO master trainer in RMUTT and participated in advancing CDIO training.

Natchaphak Meeusah got Master of Science in Mass Communication Technology and Bachelor of Technology in Multimedia Technology from Rajamangala University of Technology Thanyaburi. She works as a lecturer at the multimedia technology, faculty of Mass Communication Technology, RMUTT. Her professional interests focus on Principle of Media Production for Multimedia and Infographic. She adopted the active learning principles in her class to achieve better learning outcomes.

Corresponding author

Uravis Tangkijviwat
Faculty of Mass Communication Technology
Rajamangala University of Technology Thanyaburi
39 Rangsit-Nakornayok Rd., Klong 6,
Thanyaburi, Pathumthani, 12110 Thailand
uravis_t@rmutt.ac.th

11

DEVELOPING LOGBOOK KEEPING AS A PROFESSIONAL SKILL THROUGH CDIO PROJECTS

Sarah Junaid[1], Paul C Gorman[2], Laura J Leslie[1]

1 Department of Mechanical Engineering and Design, Aston University, UK
2 Department of Market Research, Aston University, UK

ABSTRACT

Deliberate practice, including focused practice time by students, feedback from experts, mentors, educators or peers, and student reflection (Nandagopal & Ericsson 2012) is needed in order to develop and excel in any skill. This study looks at whether deliberate and directed practice can be used to develop professional engineering skills in a CDIO teaching setting, using logbook keeping as a key example. A longitudinal analysis of logbook performance over year 1 and 2 for a graduating cohort (n = 76) was carried out. A questionnaire was given to the same cohort at the end of their final year projects to gauge logbook use during final year where no assessment was associated (36 responses). The analysis showed an improvement in logbook performance in year 1 from the first and second project, however a considerable drop in performance was noted at the start of year 2. Performance then significantly improved at the end of year 2 (ANOVA, p = 0.05). Furthermore all respondents maintained a logbook during final year although only 7 submitted their logbooks for this study. The results highlighted students maintained logbook use in final year, reflecting the positive effect of regular practice from year 1 and 2. However the drop in performance in year two may be due to lack of practice over the vacation and a discrepancy between higher performance required in year 2 and student expectations, which will be investigated further.

KEYWORDS

Projects, Skills, Standards: 3, 5, 7, 8, 10, 11, 12

BACKGROUND

Adopting the CDIO framework (Conceive-Design-Implement-Operate) at Aston has allowed for the development of professional skills while applying technical theory in team-based projects. However practice alone has little correlation to improving performance and skills competence. Whereas **deliberate practice**, i.e. practice with "deliberate effort" with the aim of improving competence and performance**,** has been shown to be effective in both (Ericcson et al. 1993; Nandagopal & Ericsson 2012). It is through deliberate practice that expertise can be developed. The ingredients for deliberate practice to occur include carrying out well-defined tasks, regular solitary practice, regular expert feedback, peer feedback and self-reflection of performance (Ericcson et al. 1993).

The skill of logbook keeping in the engineering profession is essential for documenting knowledge, primary data and technical detail that would otherwise not be captured through official company reports and other documentation (McAlpine et al. 2006). It also acts as a legal document for intellectual property protection and a key tool for project development and progress. With logbooks being an essential knowledge source of any engineering project, the habit of logbook keeping should not be underestimated. As a professional skill, logbook keeping lends itself well to being developed through regular deliberate practice.

At Aston, four major 12-week-long projects are delivered over the first two years of study on the mechanical engineering degree programs. With each project addressing different learning objectives, all share common threads in the application and development of professional and technical skills, such as logbook keeping, team working and problem solving. It is expected that with this regular repetition and formative feedback, students are engaging in deliberate practice and thus the expectation is that personal performance will improve over time. It is also expected that these skills will be utilised in future projects without explicitly setting assessments.

The hypothesis for this study is the repeated practice of keeping a logbook and feed forward assessment throughout the degree will result in retention of logbook keeping skills and an independently adopted practice of logbook use during student's Final Year Projects (FYPs), despite the lack of associated FYP logbook assessment.

AIM AND OBJECTIVES

The aim is to analyse whether assessed logbook taking from the four project modules effectively engage the students in deliberate practice and therefore develop this professional skill into their final year projects.

METHODS

Longitudinal Analysis of Previous Academic Performance

Longitudinal analyses of logbook performance and degree classification were carried out on all students who graduated in 2016-17. In the current curriculum mechanical engineering students are introduced to logbook keeping from week 1. Thereafter students are assessed with formative feedback on their logbook keeping skills throughout years 1 and 2 in a total of four CDIO projects. The logbook assessments were similar for all four CDIO projects and follows a marking matrix that reflected the requirements of the logbooks, that is: legible entries of work-in-progress, sufficient technical detail of project, project planning and weekly self-reflection of own learning (back of logbook). The relevance of logbook keeping and learning outcomes of the logbooks were covered in a short mini-lecture at the start of every project. The self-reflection element was taught using the "What? So What? Now what?" approach with exemplars.

The logbooks were marked against the rubric developed previously by academics using the CDIO framework and industry experience as a guide. The rubric was further developed using student feedback to improve the assessment and student engagement (Leslie & Gorman 2016). As well as the rubric, formative feedback was given where assessors were encouraged to use a form of the "What^2, How, Why" feedback model (Table 1 and 2). The

What[2], How, Why model allows for consistent feedback across assessors and outlines to the students: what went well, what could be improved, how the improvements could be made and why it is important. The logbooks were marked by three assessors moderated with two other assessors per project where

Two changes were implemented to the year 2 logbook assessments that must be noted: firstly, the students were told that a higher quality and performance was expected in the logbooks for year 2. This was to set a higher expectation that aligns to higher quality of work for year 2 engineering students. Secondly, the final logbook assessment (year 2, semester 2) required the inclusion of an item that was not explicitly stated but implicitly expected base on the mark scheme. The item was assessing if students used their logbooks to document test outcomes from their final product performance at the end of the module. An ANOVA test was carried out to analyse trends between logbook performances over year 1 and 2 and academic performance. The ANOVA test was chosen over using several paired t-tests to avoid increasing statistical type I error.

Table 1. Logbook assessment matrix in year 1 with What^2 How Why feedback model

	Perfect	Very Good	Good	Poor	Unsatisfactory	Unavailable
Record of all appropriate work done (including group meetings, research, designs, planning etc.) in appropriate logbook (i.e. hardback) for weeks 3-11 (MAX 10)	*[Logbook entries for all appropriate occasions & in appropriate book]*	*[Logbook entries for nearly all appropriate occasions & in appropriate book]*	*[Logbook entries for most appropriate occasions & in appropriate book]*	*[Logbook entries for some appropriate occasions OR in an inappropriate book]*	*[Logbook entries for few appropriate occasions AND in an inappropriate book]*	*[No logbook entries for any weeks regardless of book]*
Legible writing (pen not pencil) and consistent, logical layout, with dates & signatures including over any adhered inserts, mistakes crossed out not torn out or tipexed (MAX 10)	*[All legible, dated, signed + good layout]*	*[Nearly all legible, dated, signed + good layout]*	*[Mostly legible, dated, signed + reasonable layout]*	*[Areas that are illegible, mostly dated, signed &/or poor layout] layout]*	*[Mostly illegible, lack of dates & signatures, poor layout]*	*[All illegible, poor layout, no dates & signatures]*
Appropriate & easily understood drawings (sketches/technical) with sufficient detail e.g. clear annotation/dimensions as appropriate (MAX 10)	*[All drawings appropriate & with sufficient detail]*	*[Nearly all drawings appropriate & with sufficient detail]*	*[Most drawings present, appropriate & with sufficient detail]*	*[Lack of appropriate drawings or with insufficient detail]*	*[Very few drawings, inappropriate with little/no detail]*	*[No drawings & no detail]*
Sufficient/appropriate detail in descriptions & explanations (MAX 20)	*[Poss. to re-create exactly what was done/thought]*	*[Enough detail to re-create most things]*	*[Enough detail to work out most of what was done]*	*[Insufficient detail to re-create most work]*	*[Small amounts of insufficient detail]*	*[No detail at all]*
Reflections – Thoughtfulness & quality for weeks 3-11 (back of logbooks). Paragraph per week answering What? So what? Now what? (MAX 20)	*[Personal thought & development evident for all weeks]*	*[Personal thought & development mostly evident for most weeks]*	*[Personal thought & development often evident for most weeks]*	*[Personal thought & development not evident or not present for many weeks]*	*[Personal thought & development not evident or not present for most weeks]*	*[Personal thought & development not evident or not present for all weeks]*
Penalty for late submission @ 5% per day.						**Days**
PASS/FAIL - Appropriate logbook, legible, well laid out, signed & dated						
Overall grade						
Additional Comments: What went well: What could be improved: How it could be improved: Why it is important:						

Table 2. Logbook assessment matrix in year 2 with What² How Why feedback model

	Perfect	Very Good	Good	Poor	Unsatisfactory	Unavailable
Evidence of project planning, scheduling & meetings (20 marks max.)	*[Clear evidence for every week]*	*[Clear evidence for nearly every week]*	*[Clear evidence for most weeks]*	*[Clear evidence for some weeks or unclear for most weeks]*	*[Unclear evidence for some weeks only]*	*[No evidence of any planning]*
Clear, traceable and repeatable detail throughout (20 marks max.)	*[Poss. to re-create exactly what was done/thought]*	*[Enough detail to re-create most things]*	*[Enough detail to work out most of what was done]*	*[Insufficient detail to re-create most work]*	*[Small amounts of insufficient detail]*	*[No detail at all]*
Evidence of independent research, ideas & incorporation into the project (30 marks max.)	*[Clear evidence of process throughout]*	*[Clear evidence of process nearly throughout]*	*[Mostly clear evidence of process throughout or clear through most weeks]*	*[Unclear evidence of process or weeks missing]*	*[Unclear evidence of process throughout, most weeks missing]*	*[No evidence of process evident]*
Reflections – self-evaluation & areas/methods of <u>professional and technical skills</u> improvement – Thoughtfulness & quantity of entries for weeks 1-11 (in back of logbooks) (30 marks max.)	*[Useful reflections evident for all weeks]*	*[Useful reflections mostly evident for most weeks]*	*[Useful reflections often evident for most weeks]*	*[Useful reflections not evident or not present for many weeks]*	*[Useful reflections not evident or not present for most weeks]*	*[Useful reflections not evident or not present for all weeks]*
Penalty for late submission @ 5% per day.						**Days**
PASS/FAIL - Appropriate logbook, legible, well laid out, signed & dated						
Overall grade						
Additional Comments: What went well: What could be improved: How it could be improved: Why it is important:						

Final Year Questionnaires

A questionnaire was given to FYP students at the dissertation submission. The aim was to gauge self-awareness of project planning, logbook use and skills confidence retrospectively. The questionnaire design has been discussed in a previous paper (Junaid et al. *under review*). Only the logbook keeping elements of the questionnaire will be discussed here.

One of the questions on logbook use provided a list as a multiple-choice question. The list of possible uses was collated from a previous study where students were asked to elaborate on how they used their logbooks (Junaid et al. *under review*).

RESULTS

Final Year Questionnaires

Thirty-six final year students completed the questionnaire (43 % of the cohort). All respondents had used their logbooks for project planning (100 %). The lowest uses were for documenting the build (75 %) and experimental design/protocol (76 %) (Figure 1). However, only 7 students submitted their logbooks for assessment. These logbooks had an average performance of 55.5 ± 10.3 %, which were lower than their previous individual performances.

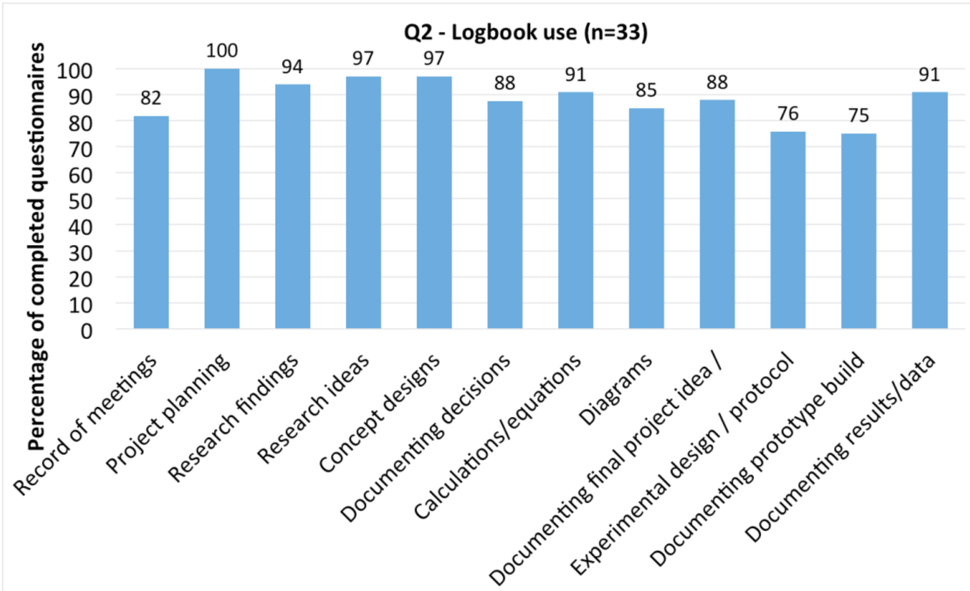

Figure 1. Logbook use at end of project (Questionnaire) showing 75-100% use.

Longitudinal Analysis of Previous Academic Performance

Longitudinal analysis of logbook performance (n = 76) showed year 1 logbook assessments marginally increased between term 1 and 2. After the six-month vacation period a considerable drop in performance at the start of year 2 was observed. Thereafter a significant improvement during year 2 was found ($p = 0.05$) (Figure 2). When split into final degree classifications, all student groups showed similar trends with most improvement seen in the Third class group (Figure 3).

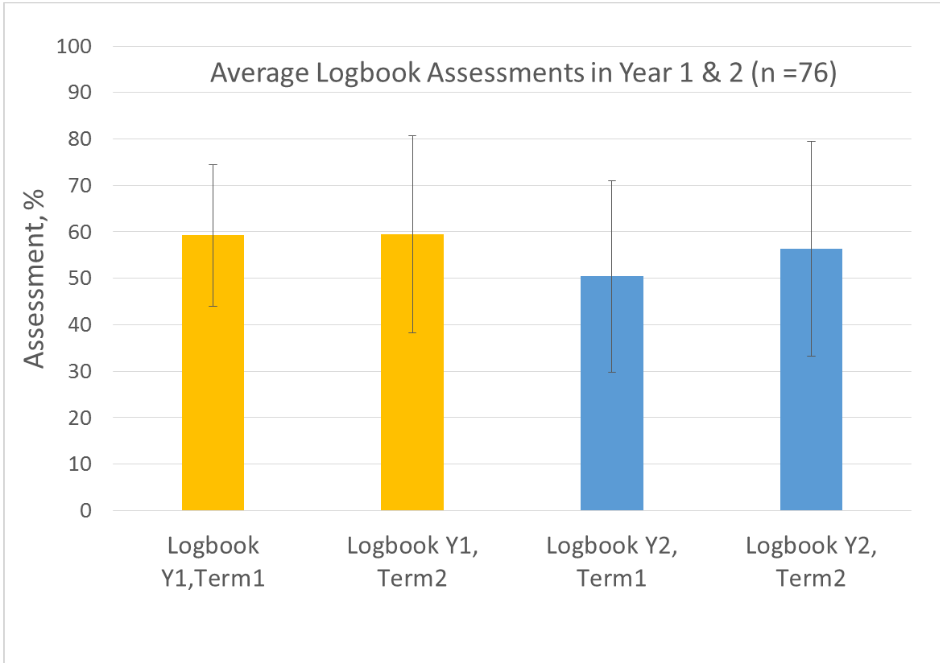

Figure 2. Average logbook performance in year 1 (yellow) and year 2 (blue) showed a significant drop in year 2, term 1, which was improved in term 2 (p = 0.05) (n = 76).

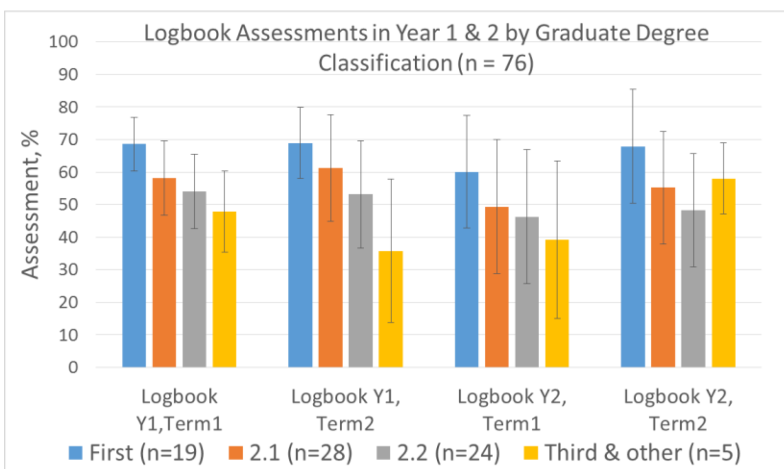

Figure 3. Logbook performances over year 1 and 2 according to degree classification showing greater improvements between assessments from Third class students (n = 76).

Year 1 and 2 Logbook Marks

Average year 1 logbook assessments showed a marginal increase in performance between term 1 and 2 (Figure 2). However, a drop in performance at the start of year 2 was observed, and a significant improvement in year 2 second term was found (p = 0.05).

Final Year Logbooks

Only 7 out of 76 students submitted their FY logbooks for the purpose of this study (9 %). Logbook assessment for these 7 logbooks had an average result of 55.5 ± 10.3 %, which was lower than their previous assessments. The same logbook assessment was used as Table 2 with the omission of the self-reflection component.

When comparing the difference in performance from the first logbook assessment (year 1, term 1) to their last logbook assessments (year 2, term 2), the students who had submitted a FY logbook had improved their performance overall by 4.1 ± 23.5 % compared to a drop of -3.3 ± 19.9 % for those who did not submit (Figure 4), although this result was not significant.

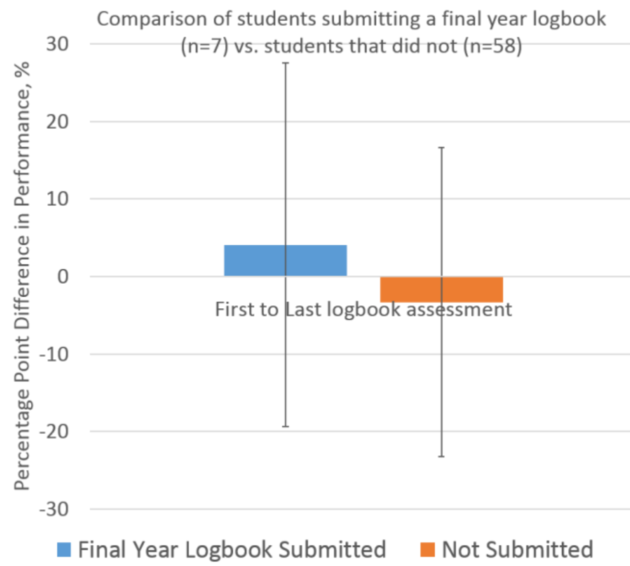

Figure 4. Students who submitted a FY logbook showed overall logbook improvements over year 1 and 2 compared to those that did not.

DISCUSSION

The analysis suggests high retention of logbook keeping in FYPs with 100 % of students using their logbook for project planning. The lowest documented logbook use was for prototype build (75 %) and experimental design/protocol (76 %), which was in part due to some projects being theory or analytical-based. However, logbook performance was lower in FY than in year 1 and 2. Accounting for degree classification, higher performing students did better in logbook keeping, however their performance did not increase or decrease significantly between assessments. The lowest performing students appeared to benefit most from deliberate practice, showing the greatest improvement. Areas that need to be addressed include lack of practice over vacation periods, motivations and engagement.

In general the longitudinal data of logbook performance over year 1 and 2 showed a pattern of improvement in each year but no positive trend over the 2 years, regardless of degree performance. In fact the significant drop in performance between year 1 and 2 reflects the lack of practice between the end of first year term 2 and start of the second year term due to the vacation period (approximately 6 months). This was consistent across high and low performing students. This may well be the primary missing element in implementing deliberate practice (Nandagopal & Ericsson 2012). Furthermore there may also be a discrepancy between higher performance required in year 2 and student expectations, which would be a compounding factor to the outcomes and will need to be investigated further.

The deliberate practice exercise does appear to be successful in continuing note keeping, as students continued in their FY projects. However, it does not appear to be successful in following good practice and maintaining good performance. It should be noted that this is based on a small number of submissions (n = 7). It appears some students are not practicing with a deliberate effort to improve although other compounding factors such as the step up in performance expected from second year engineering students must be investigated. Further improvement to the implementation of deliberate practice in logbook keeping is required such as putting more emphasis on the use of formative feedback from previous assessments to improve the next logbook assessment. It is also clear that students prioritise assessed tasks and therefore neglect useful practices that will aid their learning and performance but that do not hold any assessment, as is the case with logbook keeping in final year projects.

In this study, logbook keeping is considered a skill to be developed in itself and a valuable skill that can be taken into any engineering or technical industry (McAlpine et al. 2006). Although the relevance to industry is evident, the practice of logbook keeping was considered mundane to some students, who treated it as a means to an end (to achieve a good module mark) rather than a skill to develop and hone. Furthermore there were cases where logbook keeping was not used as designed, a work-in-progress document, but rather was retrospectively filled at the end of the week to ensure neat and presentable work for assessment. The problem of fixating on assessments is a universal issue shared across degrees. However, assessment is one of the key drivers to performance.

The element of self-reflection is also another skill that develops self-awareness, which is also being practiced in this study but rather underdeveloped. Indeed the breakdown of logbook assessment data (not presented here) showed the lowest performance in year 2 on average was in self-reflection. Despite addressing the importance of self-reflection at the start of every project and working through examples, improvement in self-reflection was modest. An interactive exercise using Kolb's cycle of learning (Kolb 1984) could be one example of developing a deeper understanding and therefore help in improving this skill.

There are several drawbacks in the study that should be noted. Firstly although a similar assessment matrix was used throughout the two years, there were minor adjustments to the assessments based on the module delivery and different teaching staff. Secondly the expectations in logbook quality and performance were raised after every iteration to reflect the competence expected at the education level taught. Finally further longitudinal analysis of the outcomes in individual performances should be carried out. This will reveal more accurately logbook performance patterns over the projects, however the analysis was beyond the scope of this paper.

CONCLUSION

Applying **deliberate practice** to logbook keeping has been effective to some extent. The highest performance was found in year 1, term 2, however a drop in performance was improved in the final CDIO project in year 2, term 2. It is hypothesised that extended periods of no practice, in this case several months, may be an important factor that negatively affects performance and therefore should be addressed. It is also predicted that the drop in performance was a reflection of setting higher expectations and a tougher marking scheme at the start of year 2 despite the assessment matrix remaining similar throughout. In the individual final year projects, all questionnaire respondents had used a logbook in some form, however performance on non-assessed logbooks showed a drop compared to year 2 assessed logbooks. The variation in logbook performance across the board will need to be investigated further for improvement. Factors such as interest, engagement, extended periods of no practice and student expectations should be investigated to improve performance. Furthermore, the emphasis of deliberate practice must be tempered with focussing on areas of improvement and engaging students with formative feedback from previous assessments.

ACKNOWLEDGEMENTS

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BIOGRAPHICAL INFORMATION

Sarah Junaid Ph. D. is a lecturer in Mechanical Engineering and Design at Aston University, UK. Her pedagogical research interests include student learning, engineering ethics and professional skills development. She is head of the Biomedical Engineering research group with an interest in biomechanical testing and computational modeling within orthopedics.

Paul Gorman is a Student Experience Manager at Aston University and oversees the evaluation of learning and teaching modules, as well as student satisfaction, across all Schools of study. His current PhD research project is centred around the marketisation of Higher Education in England. He has presented at numerous international Higher Education conferences over the last ten years.

Laura J Leslie Ph. D. is a Senior Lecturer and Deputy Head of Mechanical Engineering and Design at Aston University. Her research fields are in learning and teaching, as well as Biomedical Engineering and Materials. She has a particular interest in CDIO, active learning, teaching large cohorts and student centred learning.

Corresponding author

Dr. Sarah Junaid
Aston University
Engineering and Applied Sciences
Birmingham
B4 7ET
UK
++44 121 204 4177
s.junaid@aston.ac.uk

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EXPERIENCE IN THE DEVELOPMENT OF BACHELOR'S PROGRAM "CHEMISTRY"

Yuliya Yu. Petrova, Ekaterina V. Sevast'yanova, Viktoria V. Kraynik, Dmitry A. Kuzin, Valeria A. Bezuevskaya, Sergey M. Kosenok
Chemistry Department, Surgut State University, Russia

Alexey A. Drenin
Department of Education and Youth Policy
of the Khanty-Mansiysk Autonomous Okrug – Ugra, Russia

ABSTRACT

The challenges of regional economy and industry high demand in the engineering personnel caused the need of Bachelor's Chemistry program reforming in accordance with the best international practices. The study of industry needs for the formation of learning outcomes was carried out by questioning of the graduates and the largest companies that employed them. The questionnaire for employers consisted of general cultural and professional learning outcomes with the expected and real level. The research results have showed that personal qualities and teamwork skills take the first place among employers. Nevertheless, communication skills, design, planning and organization of the industrial enterprise, as well asexternal and social context have received the lowest assessment level of graduates and employers.

The curriculum development process is related to the first 5 CDIO standards. In order to meet Standard 1, it was stated that the Chemistry program curriculum is based on the CDIO framework as a context for industrial engineering education. To implement the Standard 2 and 3, graduate attributes were determined for the purpose of practice-oriented learning. Graduate attributes correspond with the set of knowledge and skills of CDIO Syllabus and learning outcomes. The next important stage of the work was the curriculum reforming in accordance with the graduate attributes and the learning outcomes (Standards 4-5). Thus relevant competencies of the Chemistry educational standard were compared to the attributes and the analysis of the disciplines that form these competences was carried out. As a result of the work, 25 new disciplines were introduced corresponding to the most demanded learning outcomes, 40% of curriculum was reformed, the modular approach and the practical-oriented activity were integrated.

KEYWORDS

Graduates, Syllabus and learning outcomes, curriculum reforming, standards: 1, 2, 3, 4, 5.

INTRODUCTION

Modern engineers are engaged in all phases of the products lifecycle, processes and systems which serve needs of society. That is why it is the responsibility of engineering education to support their preparation for this. In Russia existing Bachelor's programs linked to Chemistry and Chemical Engineering content are often much focused on fundamental knowledge itself, so that students graduate as professionals who know how to solve pre-defined technical problems. Students of such programs seldom practice entrepreneurial, communication and innovation skills at the level that is expected and needed in working life.

The CDIO Initiative focuses on modernizing engineering education by introducing such skills and thinking into technical programs and courses. By implementing CDIO, students will be able to encounter more real-life problems, which are cross-disciplinary and are set in the context that may include social, legal, environmental and business aspects. Such problems are often characterized as complex and ill-defined, and there can be one or many solutions to be of importance in the light of specific conditions. Members of the CDIO Initiative have the opportunity to continuously develop as CDIO collaborators and regularly develop materials and approaches to share with others (Crawley et al., 2014).

SURGUT STATE UNIVERSITY

Surgut University is the leading university in Khanty-Mansiysk Autonomous Okrug (Russia). Surgut University joined the CDIO initiative in June 2017 at 13th International CDIO Conference in Calgary with three education programs, including the reformed bachelor's program Chemistry.

Khanty-Mansiysk Autonomous Okrug - Ugra is one of the strategic regions of Russia, providing energy security of the country and being the largest oil producing region of the state and the world. The strategy of socio-economic development of the region outlines the following: "The peculiarity of the innovative scenario is that the renewal of the structure and content of education should be planned for the future development of the labor market in accordance with international standards. The innovative scenario implies the need to ensure high rates of development of educational programs aimed at staffing the industries that generate innovation and, in general, the service sector".

Surgut State University, founded in May 1993, is the largest university in Ugra, which trains students in a number of fields of science and technology. It offers a wide range of bachelor's and master's programs, including ones in chemistry and analytical chemistry. The main goal of the university development is to transform into the university of a new type, supporting and providing innovative economic development of the region.

Alumni of the Surgut State University chemistry program work as engineers at the largest oil and gas companies and power stations in the field of quality control of oil and gas products, control of processes in oil recovery (EOR and IOR) and oil and gas processing technology. More than 40% of graduates work at JSC "Surgutneftegas", 24% - at JSC "Gazprom", about 20% - at the electric power industry. Graduates are employed in regional industry mainly as laboratory assistants in chemical analysis; laboratory assistants for sampling; laboratory assistants for quality control; laboratory engineers; chemical engineers and environmental engineers. Therefore, the reforming of educational programs in the field of chemistry based on practice-oriented principles has become an urgent task of modern chemical education.

What were the reasons for becoming a CDIO member?
- Improving quality of engineering education programs to meet the demand for high-skilled employees.
- Students' soft skills development.
- Reviewing engineering educational programs and establishing learning outcomes in close contact with stakeholders.
- Readiness of students to complete full lifecycle projects in a team.
- Integration of the university into the world scientific and educational environment via information and ideas exchange with other CDIO members.
- Enhance competitiveness of the university and its graduates on the national and global scale.

CURRICULUM OF THE BACHELOR'S DEGREE PROGRAM ON CHEMISTRY

The analysis of Chemistry program has showed that its strengths are the interdisciplinarity of project-oriented learning and the project activity of chemistry students and the improved pedagogical competences of the teaching staff, trained in distance education technologies at Moscow State University and in design of educational programs in accordance with CDIO principles at Tomsk Polytechnic University. Weaknesses of the program are associated with the lack of soft skills (interpersonal competencies) and methods for evaluating programs, the need to modernize the working space for student design activities and to improve the methods for evaluating teaching, as well as partial application of active teaching methods.

The study of the needs of industry for the formation of learning outcomes was carried out by questioning the largest companies that hire graduate chemists and graduates themselves. So the questionnaire for employers consisted of general cultural and professional formed learning outcomes with the expected and real level on a 5-point scale (Table 1).

The table (Table 2) shows the expected level of professionalism in the opinion of the industry and graduates. The research results have showed that personal qualities (1, 2, 4, 7-11) and teamwork skills (3, 14) take the first places among employers. However, communication skills (5), entrepreneurial and business context (14), as well as external and social context (6) have received the lowest assessment level of the graduates' and employers' expected professionalism.

Table 1. Questionnaire for employers for the definition of the learning outcomes formation level

№	Learning outcomes	Level of formation											
		Real						Expected					
1	Manage your time, build and implement the trajectory of self-development based on the principles of life learning	0	1	2	3	4	5	0	1	2	3	4	5
2	Demonstrate knowledge of social, ethical, cultural and economic aspects of professional activity	0	1	2	3	4	5	0	1	2	3	4	5
3	Effectively work independently and in team, including interdisciplinary and multicultural environment	0	1	2	3	4	5	0	1	2	3	4	5
4	Competently execute and report the results of work in written and oral form using the appropriate technical terminology	0	1	2	3	4	5	0	1	2	3	4	5
5	Active proficiency in the main European languages at the level that allows to study information and present results of professional activity	0	1	2	3	4	5	0	1	2	3	4	5
6	Use methods and means of health promotion, demonstrate commitment to a healthy lifestyle	0	1	2	3	4	5	0	1	2	3	4	5
7	Apply the knowledge of theoretical foundations of natural science disciplines, including the fundamental sections of chemistry in professional activity	0	1	2	3	4	5	0	1	2	3	4	5
8	Demonstrate a systemic interdisciplinary understanding of engineering sciences as applied to solve production problems	0	1	2	3	4	5	0	1	2	3	4	5
9	Plan and conduct laboratory tests using modern instrumentation, observe health and safety standards in chemical production, meet environmental protection requirements	0	1	2	3	4	5	0	1	2	3	4	5
10	Select and use, on the basis of fundamental and specialized knowledge, necessary reagents, equipment and techniques for conducting complex practical engineering activities, taking into account economic, environmental, social and other requirements	0	1	2	3	4	5	0	1	2	3	4	5
11	Interpret the data obtained as a result of theoretical and experimental studies in terms of their significance	0	1	2	3	4	5	0	1	2	3	4	5
12	To carry out, correct and develop the technological processes of chemical production	0	1	2	3	4	5	0	1	2	3	4	5
13	To plan and organize the work of industrial divisions	0	1	2	3	4	5	0	1	2	3	4	5
14	Demonstrate leadership in engineering activity and engineering entrepreneurship, responsibility for subordinates and the result of production activities; willingness to follow the corporate culture of the organization	0	1	2	3	4	5	0	1	2	3	4	5

Table 2. The level of learning outcomes formation

№ of learning outcomes	The levels of learning outcomes formation			
	Employers		Graduates	
	Real	Expected	Real	Expected
1	4,0 ± 0,5	4,5 ± 0,6	2,7 ± 1,0	3,5 ± 1,1
2	4,0 ± 0,6	4,0 ± 0,5	2,2 ± 1,1	2,5 ± 1,3
3	5,0 ± 0,9	4,0 ± 0,5	2,8 ± 1,1	2,2 ± 1,2
4	4,5 ± 0,5	4,0 ± 0,6	3,2 ± 0,9	3,3 ± 1,1
5	2,0 + 0,5	3,5 ± 1,3	1,5 ± 0,8	2,5 ± 1,5
6	2,0 ± 1,1	3,5 ± 0,9	2,0 ± 1,1	2,5 ± 1,6
7	5,0 ± 1,1	3,5 ± 0,8	3,2 ± 0,9	3,3 ± 1,1
8	5,0 ± 1,1	4,0 ± 0,5	2,7 ± 1,0	3,3 ± 1,1
9	5,0 ± 0,9	3,5 ± 0,8	3,3 ± 0,8	3,7 ± 1,0
10	5,0 ± 1,1	4,0 ± 0,5	3,5 ± 1,0	3,7 ± 0,8
11	5,0 ± 1,5	4,0 ± 0,0	3,3 ± 1,1	3,7 ± 1,0
12	2,0 ± 0,0	4,0 ± 1,0	2,2 ± 0,8	3,0 ± 1,3
13	3,5 ± 1,7	4,0 ± 0,8	2,0 ± 1,0	2,7 ± 1,6
14	4,0 ± 1,6	4,0 ± 0,0	2,3 ± 1,1	3,0 ± 1,3

DEVELOPMENT OF CURRICULUM OF BACHELOR'S PROGRAM ON CHEMISTRY

The CDIO Initiative started in the year 2000 with the aim to reform engineering education for a better professional preparation. The vision of CDIO is to educate students to master a deeper working understanding of technical fundamentals, the ability to lead in the creation & operation of products and systems, and an understanding of the role and strategic value of research (Berggren *et al*., 2003; Crawley *et al*., 2014).

The 12 CDIO standards disclose the philosophy of the program (Standard 1), the development of curricula (Standards 2, 3 and 4), the implementation of project activities and requirements for working space (Standards 5 and 6), teaching and learning methods (Standards 7 and 8), teacher training (Standards 9 and 10), as well as the assessment of learning outcomes and the overall program (Standards 11 and 12).

It is worth noting that the CDIO Syllabus is not a defining feature of CDIO. Each institution must formulate programme goals considering, e.g. stakeholder needs, national and institutional context, level and scope of programmes, and subject area. To accommodate diversity, the CDIO syllabus is offered as an instrument for specifying local programme goals by selecting topics and making appropriate additions in dialogue with stakeholders. As such, it has served as a reference for a multitude of engineering programmes and for diverse contexts and purposes (Edström *et al*. 2014).

The curriculum development process is related to the first 5 CDIO standards. In order to meet Standard 1, it was stated that the curriculum of the Bachelor's program Chemistry is based on the CDIO framework as a context for industrial engineering education. In 2017 Surgut University joined the CDIO Initiative and the first set of students for the Chemistry program was implemented.

For the implementation of Standard 2 in the University attributes of the graduates (Table 3) "for the purpose of practice-oriented training of graduates" - who are ready for real-life work, were determined. Attributes of graduates correspond with the set of knowledge and skills of CDIO Syllabus and learning outcomes.

Table 3. Attributes of the Bachelor’s program Chemistry graduates

№	Attribute	Description
1	Graduates with practice-oriented training	Ability to think, produce, design, solve problems, collaborate and meet requirements of industry
2	Knowledge	Knowledge of basic sciences, application of in-depth knowledge, integration of learning experience
3	Professional skills	Basic and advanced practical skills, meeting the requirements of industry in accordance with the Bachelor of Chemistry qualification
4	Personal and interpersonal skills	Knowledge of foreign language;
		Communication and Information Technology;
		Teamwork;
		Learning to learn;
		Analytical thinking and problem solving skills;
		Manner and behavior in the industrial sphere;
		Commitment to discipline and organization;
		Social activity and interest

Standard 3: It can be seen from the survey that top of 5 expectations from industry representatives are related to teamwork skills, personal qualities, key knowledge of the engineering basics, production and communication skills. The head of the educational program and the staff of Chemistry Department have worked to identify inconsistencies and eliminate shortcomings.

The next most important stage of the work was the reforming of the educational program in accordance with certain attributes of the graduate and the learning outcomes. To do this, we have compared relevant competencies of the educational standard 04.03.01 Chemistry (Russia) with the attributes of a graduate and the analysis of the disciplines that form these competences have been carried. As a result of this work, new disciplines were introduced (Figure 1), corresponding to the most demanded learning outcomes of program stakeholders. 40% of the educational program have been reformed as a result of this work (Figure 2): 25 new disciplines have been introduced, a modular approach has been integrated (in mathematics and physics courses), practice-oriented activities (coursework and projects, project activity, research activity) and interdisciplinarity.

Future Work

Further implementation of CDIO standards in the Bachelor’s program on Chemistry in the current 2018 provides:

- Development of the content of the program disciplines in accordance with certain learning outcomes;
- Expanding the use of active teaching methods in the educational process;
- Modernization of the working space (educational environment) for the implementation of project-oriented learning;

- Development of distance courses of the program disciplines.

Prospects for CDIO engineering education development at the Institute of Natural and Technical Sciences are reflected in the development program until 2020 and envisage the reforming of the educational programs "Technospheric Security" and "Ecology and Nature Management" in the context of the engineering education of the International CDIO Initiative.

Learning outcomes	New disciplines	Attributes
1-3, 6, 13, 14	*General cultural competences:* Economics and management at chemical industry enterprises; Legal basis of professional activity; Foreign language for special purposes; Ethics of business communication; Conflictology; Ethics and culture of tolerance; Psychology in professional activity	2, 4
4, 5, 7, 8, 9	*General professional competences:* Regulation and reduction of environmental pollution; Information Security; Introduction to project activities; Chemical Engineering	1-4
9-12	*Professional competences:* Chromatographic control of oil and gas production and processing; Organization of analytical control at production, environmental monitoring, biotechnology, clinical diagnostics; Protection of Intellectual Property Rights; Sampling and sample preparation; Petroleum chemistry; Chemistry and technology of oil and gas processing; EOR methods; Basics of industrial analysis; Quality control	1-3

Figure 1. New disciplines of the curriculum Chemistry

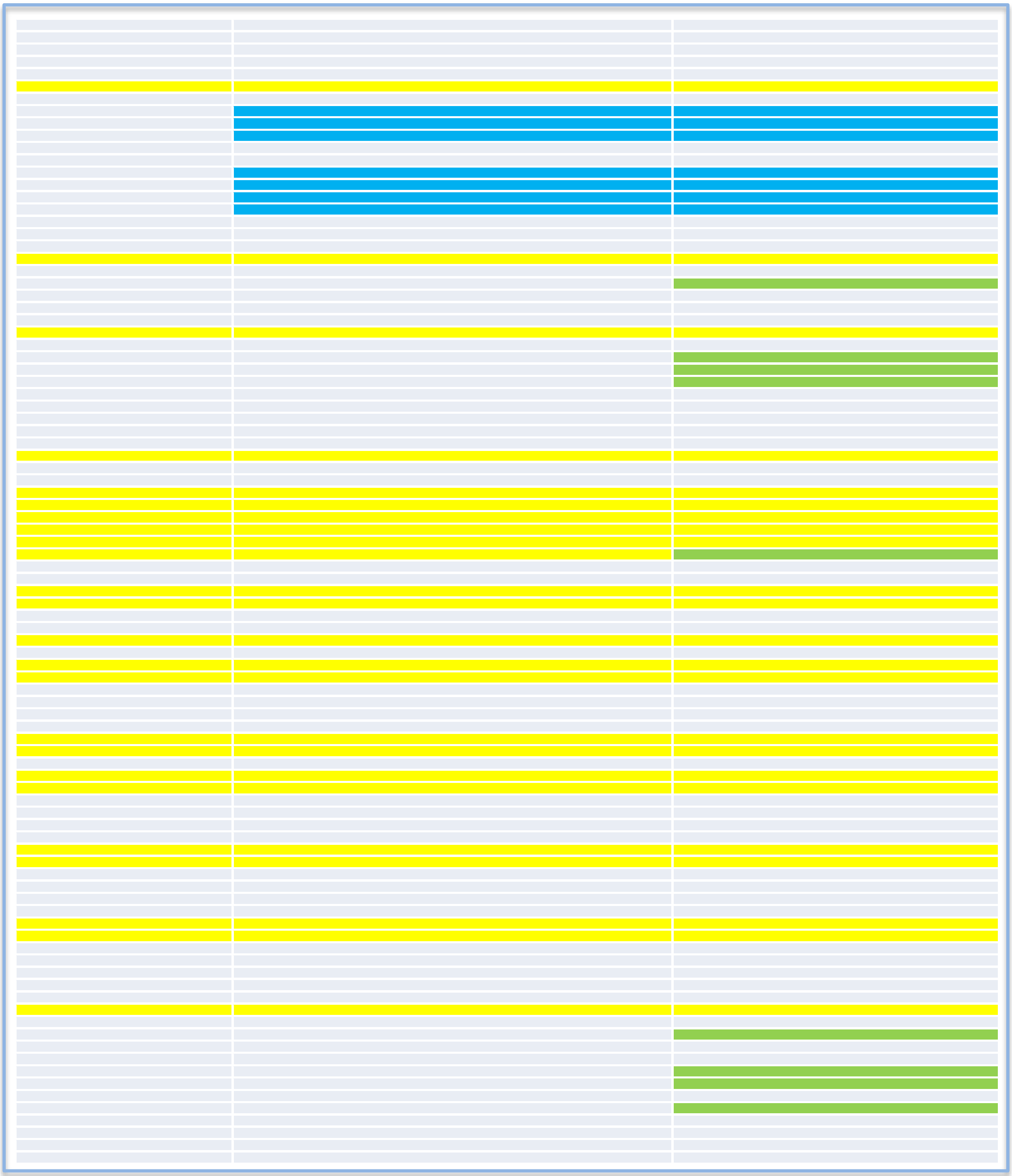

Figure 2. Color diagram of the curriculum Chemistry (yellow: new disciplines, blue: modules on mathematics and physics, green: coursework and projects, project activity, practices, research activity)

CONCLUSION

The CDIO team includes the leadership of the university represented by rector and pro-rector for development, director of Institute of Natural and Technical Sciences, teachers of chemistry department, representatives of the region's employers, including university graduates, and chemistry students themselves. Since 2016 a lot of work has been done: the Bachelor's program on Chemistry in the context of industrial engineering education has been revised and the curriculum has been reformed (standards 1-5).

In 2017 at the 13th International CDIO Conference (Calgary, Canada, June 18-22, 2017) Surgut University joined the International CDIO Initiative and in September of 2017 the first group of students began studying the reformed program.

In order to drive a continuous development and creation of sustainable education in Chemistry with true industrial involvement, a longer commitment of CDIO Initiative support is needed. This will further require wider faculty training with CDIO pedagogics, innovative laboratory development, and industry driven project course development within Chemistry.

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BIOGRAPHICAL INFORMATION

Yuliya Yu. Petrova, Ph. D. is an Associate Professor in Analytical Chemistry and Director of Institute of Natural and Technical Sciences, Surgut State University. She collaborates with universities in Russia on topics related to curriculum design and the improvement of teaching and assessment. Her current research focuses on surface molecular imprinting method and geochemistry of unconventional reservoirs.

Ekaterina V. Sevast'yanova, Ph.D. is an Assistant Professor in Physical Chemistry and Head of the Programme in Chemistry (Bachelor's Degree) at the Department of Chemistry, Surgut State University. Her current research focuses on synthesis of layered double hydroxide with magnetic properties and on curriculum development methodology.

Viktoria V. Kraynik, PhD is a Senior Lecturer in Chemistry and a Learning and Assessment Specialist in the Department of Chemistry at the Surgut State University. She collaborated with regional stakeholders on topics related to curriculum design and the improvement of teaching and assessment.

Dmitry A. Kuzin, PhD is an Assistant Professor at the Department of Automation and Computer Systems, Surgut State University. He collaborates with the Department of Chemistry in curriculum design and the improvement of teaching.

Valeria A. Bezuevskaya, PhD is a Pro-rector for development of the Surgut State University. She collaborates with universities in Russia on topics related to the development of engineering education and the improvement of teaching and assessment. Her current research focuses on problem of training teachers for the vocational education system.

Sergey M. Kosenok, Doctor of pedagogical sciences, Full Professor is a Rector of the Surgut State University. He collaborates regularly with universities of CDIO Initiative on topics related to the development of engineering education and he heads the CDIO team of the Surgut State University. His current research focuses on politics of regionalization of education in the university activity.

Alexey A. Drenin, Ph. D. is a Director of Department of Education and Youth Policy of the Khanty-Mansiysk Autonomous Okrug - Ugra. In 2016 he was the initiator of reforming the Bachelor's Programme Chemistry according with CDIO standards. He is the author of the concept of the scientific and educational complex of the Campus-SurGU. His current research focuses on structural diversity and biological activity of flavonoids and isoflavonoids of plants Trifolium L.

Corresponding author

Dr. Yuliya Yu. Petrova
Surgut State University
1 Lenin Avenue
Surgut, Tjumen obl., Russia 628412
+7-982-185-8382
yyp.71@mail.ru

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THE INTEGRATION OF CDIO STANDARDS IN THE APPLICATION OF PROJECT BASED LEARNING AS A HANDS-ON METHODOLOGY: AN INTERDISCIPLINARY CASE STUDY IN PRODUCTION ENGINEERING

Sergio Ricardo Mazini, Sueli Leite, Priscilla Aparecida Vieira de Moraes, Márcia Maria Teresa Baptistella, Rangel Ferreira do Nascimento

Departament of Industrial Engineering, University Center Toledo Araçatuba

ABSTRACT

The use of active learning methodologies is being discussed more and more by higher education institutions in Brazil and in the world. Technological advances and the differentiated profile of new students are some of the reasons why many institutions are rethinking their teaching and learning processes. In this context, the use of active methodologies in engineering courses has been the subject of constant discussions and questioning by teachers and institutions.

The objective of this work is to report the experience in the application of Project Based Learning in the production engineering course of a University Center in Brazil, which allowed the integration of some CDIO Standards. The main motivation for choosing Project Based Learning was the application of interdisciplinarity and also the need to use a hands-on methodology that would put into practice the theories discussed throughout the project.

The case study presents an overview of the application of Project Based Learing through an integrative project of the 6th semester of the production engineering course that had as its theme the manufacture of orthoses that made possible integration of the disciplines in the semester, integration with the physiotherapy course of the institution. Throughout the case study the integration of some CDIO Standards is also presented.

The method used to collect the data to demonstrate the students' perspective was a two-part survey: at the beginning and at the end of the development of the integrating project. The information obtained shows a greater engagement of students and improvement in the teaching and learning process. The application of new teaching and learning methodologies should be widely discussed with the teachers and coordinators of the courses, in order to first identify which competences they intend to develop and identify the methodology that best applies. The alignment and qualification of all teaching staff for the use of new methodologies in the classroom is of paramount importance and the educational institution must provide actions that contribute to the implementation of new methodologies and resources in the teaching and learning process.

KEYWORDS

Project-based learning, integrative projects, interdisciplinarity, engineering teaching, Standards: 2, 3, 5, 6, 7, 8, 11

INTRODUCTION

The constant changes that occur as a result of the technological advances demand more and more professionals prepared and with a differentiated profile for work in the labor market. The training of an engineer needs to be as complete as possible encompassing both technical competencies and behavioral skills, thus requiring constant changes to adapt to this new reality.

In this context, the use of active learning methodologies play an important role in the formation of the professional future. Among these methodologies is Project Based Learning that places the student at the center of the learning process, identifying a potential problem that can be solved through a project (Lima et al., 2014). Masson et al. (2012) proposes that project-based learning is a systemic approach, involving students in acquiring knowledge and skills through a process of investigation of complex issues, authentic tasks and products, carefully planned for efficient and effective learning. effective.

The application of interdisciplinary projects in undergraduate courses allows a greater commitment on the part of the students, as well as a greater motivation for the studies (Koch et al., 2016). The learning practices provided by project-based learning are being studied and demonstrate the benefits of applying to students. (DeFillippi, 2001).

The CDIO ™ initiative addresses this reality and aims to contribute to the training of the next generation of engineers through 12 standards to describe CDIO programs. These guiding principles were developed in response to program leaders, alumni, and industry partners who wanted to know how they would recognize CDIO programs and their graduates.

The objective of this work is to report the experience in the application of Project Based Learning in the production engineering course of a University Center in Brazil, which allowed the integration of some CDIO Standards.

INTEGRATOR PROJECT

The Production Engineering course at the Toledo Araçatuba University Center - UNITOLEDO, located in the city of Araçatuba, state of São Paulo - Brazil, was launched in 2013, after a survey was made in the region on the demand for qualified professionals to work in the industry regional.

The application of Project-Based Learning reported in this study occurred in the second half of 2017, at the time, with the 6-semester class through an Integrator Project, developed during the semester, whose main objectives were: integration between the subjects of the the use of a hands-on methodology in which Project-Based Learning and the development of skills were used, in addition to the integration with another course of the institution, Physiotherapy, which assisted in the elaboration of the new product.

Table 1 below presents the competencies proposed for development throughout the integrative project.

Table 1. Skills to be developed in the integrative project.

COMPETENCES AND PERSONAL AND PROFESSIONAL ATTRIBUTES (to be developed)	**Reasoning of Engineering and Problem Solving** (Identification and formulation of the problem by models, estimates, analysis and recommendation of solutions)
	Experimentation and Discovery of Knowledge (Hypothesis Formulation and Testing, Survey of Electronic Literature, Experiments)
	Systemic Thinking (Holistic, vision of the whole, urgency, prioritization, focus, trade-offs and balance in resolution)
	Personal Skills and Attitudes (Initiative and willingness to take risks, perseverance and flexibility, creative, critical, time and resource management)
	Skills and attitudes Professional (Ethical behavior, integrity, responsibility, continuous updating, proactive career planning)
INTERPERSONAL SKILLS (to be developed)	**Teamwork** (Effective Leadership Team Formation, evolutionary technical operation)
	Communication (Strategy and structure through writing, oral, graphic and interpersonal)

The professor responsible for conducting the Integrator Project was the professor of the discipline called Manufacturing and Construction Processes II, whose main objective is to present the theory and practice of the development of new products of several industrial segments. The other disciplines participating in the Integrator Project, which are part of the semester of the sixth semester of Production Engineering, and their contributions can be observed in table 2 below.

Table 2. Disciplines participating in the Integrator Project.

SUBJECTS	**CONTRIBUTION**
Production Planning, Scheduling and Control I	Determine product data sheet and manufacturing process.
Inventory Management	Determine the standardization and coding of materials, components and finished product, as well as stock control.
Supply Chain Management	Determinar a necessidade e gestão dos fornecedores de materiais.
Information systems	Determine the need and management of materials suppliers.
Manufacturing and Construction Process II	Basic discipline for the realization of the Integrator Project. Students will develop a new product through the real needs presented in the integrator project.
Strength of Materials II	Determine the strength of the materials used.
Prosthesis and Orthesis (course of Physical Therapy)	Assist in the development and validation of new products.

As a theme for the application of Project-Based Learning, the orthotics segment was chosen, where students, divided into teams of no more than 5 members, should develop an orthosis to meet a demand from the institution's physiotherapy clinic.

The use of active learning methodologies in the course of Production Engineering has been discussed by the course collegiate, which brings together the course coordinator, teachers and a student representative. The teacher responsible for the discipline that led the project during the semester, held some meetings with the other teachers of said semester in order to present the proposal and seek contributions from the other disciplines for the project that was developed.

The steps of the integrator project were based on the principles of the CDIO framework, as reported by Edström & Kolmos (2014), and can be visualized in table 3 below:

Table 3. Stages of project development.

STAGE CDIO	**MAIN ACTIONS AND DELIVERIES**
CONCEIVE	1- Generation of concept (term of project opening) 2- Project Planning (project scope, product scope)
DESIGN	3- Information Project (QFD) 4- Conceptual Design (EAP, BOM) 5- Detailed Design (Model, FMEA, Drawings)
IMPLEMENT	6- Preparation for Production (cost, process, full-size prototype)
OPERATE	7- Product Launch (marketing) 8- Follow Product / Process (product performance and customer satisfaction) 9- Plan Product Discontinuation

The manufacturing process and the developed product were manufactured in the Laboratory of Production Practices II of the Production Engineering course and are presented in Figure 1 below.

Figure 1. Products developed in the Integrator Project.

According to the data collection method to demonstrate student expectation and perception, and consequently the development of competencies, Table 4 below presents the data collected from the 18 students participating in the project, at the beginning of the project, with the objective of collecting expectations of students. The table shows the number of responses at each of the levels of development of this competence.

Table 4. Data collected with the expectation of the 18 students before the project.

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SKILLS	Be experienced or exposed to ..	Being able to participate and contribute to ..	Being able to understand and explain ..	Be skilled in the practice or application of..	Being able to lead or innovate in ..
SKILLS AND ATTITUDES: PERSONAL AND PROFESSIONAL					
Reasoning of Engineering and Problem Solving (Identification and formulation of the problem by models, estimates, analysis and recommendation of solutions)	10	3	2	2	1
Experimentation and Discovery of Knowledge (Hypothesis Formulation and Testing, Survey of Electronic Literature, Experiments)	7	3	3	5	
Systemic Thinking (Holistic, vision of the whole, urgency, prioritization, focus, trade-offs and balance in resolution)	6	6	3	3	
PERSONAL SKILLS AND ATTITUDES (Initiative and willingness to take risks, perseverance and flexibility, creative, critical, time and resource management)	8	3	5	2	
Skills and attitudes PROFESSIONAL (Ethical behavior, integrity, responsibility, continuous updating, proactive career planning)	3	9	2	4	
INTERPERSONAL SKILLS: COMMUNICATION AND MULTIDISCIPLINARY TEAM					
Teamwork (Effective Leadership Team Formation, evolutionary technical operation)	2	7	9		
Communication (Strategy and structure through writing, oral, graphic and interpersonal)	8	3	5	2	

At the end of the project, the data were collected again with the objective of collecting the students' perceptions, which shows an evolution by the total number of students who demonstrated a higher level of proficiency after the project was carried out. The data obtained can be visualized in Table 5 below.

Table 5. Data collected with the perception of the 18 students after the project.

SKILLS	Be experienced or exposed to ..	Being able to participate and contribute to ..	Being able to understand and explain ..	Be skilled in the practice or application of..	Being able to lead or innovate in ..
SKILLS AND ATTITUDES: PERSONAL AND PROFESSIONAL					
Reasoning of Engineering and Problem Solving (Identification and formulation of the problem by models, estimates, analysis and recommendation of solutions)			2	7	9
Experimentation and Discovery of Knowledge (Hypothesis Formulation and Testing, Survey of Electronic Literature, Experiments)			3	12	3
Systemic Thinking (Holistic, vision of the whole, urgency, prioritization, focus, trade-offs and balance in resolution)		1	3	7	7
PERSONAL SKILLS AND ATTITUDES (Initiative and willingness to take risks, perseverance and flexibility, creative, critical, time and resource management)		1	1	4	12
Skills and attitudes PROFESSIONAL (Ethical behavior, integrity, responsibility, continuous updating, proactive career planning)	1		1	6	10
INTERPERSONAL SKILLS: COMMUNICATION AND MULTIDISCIPLINARY TEAM					
Teamwork (Effective Leadership Team Formation, evolutionary technical operation)		1		9	8
Communication (Strategy and structure through writing, oral, graphic and interpersonal)	1	1	3	8	5

The integrative project presented in this study demonstrates the integration and application of some CDIO Standards, as presented in Table 6 below:

Table 6. CDIO Standards developed in the integrator project.

CDIO Standards	Description	Note
2. Learning Outcomes	Specific, detailed learning outcomes for personal and interpersonal skills, and product, process, and system building skills, as well as disciplinary knowledge, consistent with program goals and validated by program stakeholders	We identified the personal and interpersonal skills to be developed throughout the project, as well as the skills of building products, processes and systems.
3.Integrated Curriculum	A curriculum designed with mutually supporting disciplinary courses, with an explicit plan to integrate personal and interpersonal skills, and product, process, and system building skills	The course subjects allow integration for the development of multidisciplinary projects.
5.Design-Implement Experiences	A curriculum that includes two or more design-implement experiences, including one at a basic level and one at an advanced level	The disciplines allow each semester to elaborate integrative projects with the theme of development of new products, processes or systems.
6.Engineering Workspaces	Engineering workspaces and laboratories that support and encourage hands-on learning of product, process, and system building, disciplinary knowledge, and social learning	The institution's laboratories used in the project allow the production of products from several industrial segments.
7. Integrated Learning Experiences	Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal and interpersonal skills, and product, process, and system building skills	The integration with another course of the institution throughout the integrating project made possible the exchange of information and experiences that contributed to the development of established competencies.
8.Active Learning	Teaching and learning based on active experiential learning methods	The use of Project Based Learning enabled the use of active learning methodologies including students at the center of the teaching and learning process.
11.Learning Assessment	Assessment of student learning in personal and interpersonal skills, and product, process, and system building skills, as well as in disciplinary knowledge	Data collection before and after the project made it possible to evaluate the evolution of the students and also of the learning process.

DISCUSSIONS AND CONCLUSIONS

With the application of project based learning through the integrator project applied in a class of students of the course of Production Engineering, it is possible to identify an evolution of the students who have evaluated themselves in two moments of the application of the project, since in the second evaluation made at the end of the project the proficiency level of the competences had a greater weight than the first evaluation made before the beginning of the project.

As for the evaluation of the educational process that was discussed among the professors who ministered the disciplines integrating the project, the application of the project based learning made it possible to integrate the contents of most of the disciplines of that semester, taking the subject of multidisciplinarity in the discussions of the groups of students .

The case presented in this article demonstrates the contribution that the active learning methodologies can provide the improvement of the teaching and learning process, according to the information obtained in the data collections with the students. A very important factor that has been the subject of doubts in higher education, particularly in engineering courses, is precisely the way to apply the practice along with the theory exposed in the classroom. Another issue is the development of behavioral skills such as leadership, teamwork and conflict resolution, which are just as important as technical skills and the use of active learning methodologies provide support for this development, generating better results in the teaching and learning process .

The application of new teaching and learning methods should be widely discussed with teachers and course coordinators in order to identify first what skills they intend to develop and how to identify which methodology is best applied. Alignment and training of all faculty for the use of new methodologies in the classroom is extremely important and the educational institution should provide actions that contribute to the implementation of new methodologies and resources in the teaching and learning process. The experience acquired in the application of project-based learning brought satisfactory results, which allowed several discussions between teachers and course coordinator in the methodology for application in the next semesters and also for its application in other engineering courses of the institution. Additional research should be done to identify the profile of the student entering higher education in order to assess the paradigm shift and the problem of drop-out and how the use of active learning methodologies can contribute positively to these issues.

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BIOGRAPHICAL INFORMATION

Sergio Ricardo Mazini is a coordinator and professor of the course of production engineering, holds a master's degree in production engineering. He participates in the Nucleus of Innovation and Academic Formation of the institution that is responsible for the continued formation of the teachers.

Sueli Leite is a professor of mechanical engineering and production engineering, holds a master's degree in mechanical engineering. She has participated in other initiatives related to the use of project based learning in the production engineering course.

Priscilla Aparecida Vieira de Moraes is a professor of engineering in production and mechanical engineering, holds a master's degree in production engineering. She has participated in research activities related to topics involving production engineering.

Márcia Maria Teresa Baptistella is a professor of engineering in production and analysis and systems development, holds a master's degree in production engineering. She has participated in the structuring teaching nucleus of the course of production engineering assisting in the conduction and implementation of actions of the pedagogical project of the course.

Rangel Ferreira do Nascimento is a professor of mechanical engineering and production engineering, holds a Ph.D. in mechanical engineering. He has participated in integrative projects helping in the integration with other courses of the institution.

Corresponding author

Sergio Ricardo Mazini
University Center Toledo Araçatuba
Rua Antônio Afonso de Toledo, 595
Araçatuba, São Paulo, Brazil
CEP: 16.015-270
55-18-36367083
mazini.prof@toledo.br

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COORDINATED DESIGN AND IMPLEMENTATION OF "BIOENGINEERING DESIGN" AND "MEDTECH" COURSES BY MEANS OF CDIO PROJECTS LINKED TO MEDICAL DEVICES

Andrés Díaz Lantada*, Luis Ignacio Ballesteros Sánchez, Enrique Chacón Tanarro, Ana Moreno Romero, Rafael Borge García, Miguel Ángel Peláez García, Rafael Ramos Díaz, Jesús Juan Ruíz

Escuela Técnica Superior de Ingenieros Industriales (ETSII),
Universidad Politécnica de Madrid (UPM)
c/ José Gutiérrez Abascal 2, 28006 Madrid, Spain
*Contact: adiaz@etsii.upm.es

ABSTRACT

Biomedical engineering is aimed at the application of engineering principles, methods and design concepts to medicine and biology for healthcare purposes and is directly connected with professional practice in the medical device industry. Industrial and management engineers, due to their broad education and global view, can significantly contribute to the advances in the biomedical field, especially if they learn some essential biomedical concepts and train specific professional skills during their university degrees. In this study we present the coordinated design and implementation of two courses devoted to the biomedical engineering field, namely "Bioengineering Design" and "MedTech", included in the Master's Degree in Industrial Engineering and in the Master's Degree in Engineering Management respectively, both at the ETSI Industriales from Universidad Politecnica de Madrid. These courses follow the framework established by the Industriales Ingenia Initiative, which is completely aligned with the spirit of the International CDIO Initiative. Students from both courses collaborate in teams and live through the complete development life cycle of innovative medical devices (linked to relevant health concerns), from the product planning and specification stages, through the conceptual and basic engineering phases, including final validations with real prototypes, towards pre-production and commercialization considerations. These projects stand out for their degree of complexity and counting with such multidisciplinary teams, in which students from different backgrounds and with varied skills intimately collaborate, constitutes an interesting strategy for addressing the life cycle of innovative biodevices with a holistic approach. Socio-economic issues, technical demands, environmental sustainability and overall viability are among the key aspects assessed by the students following systematic design methodologies. The team of professors has also lived somehow through a complete and quite challenging CDIO cycle, during the conception, curricular design, first implementation and assessment of these synchronized teaching-learning experiences, but the improvement of students' learning outcomes and the inspiring ambience of collaboration created are worth the efforts. Main benefits, lessons learned and future challenges, linked to these courses and to the collaborative presented strategy, are analyzed, taking account of the available results from 2017-2018 academic year.

KEYWORDS

Biomedical engineering, CDIO implementation, Case studies & best practices, Integrated learning experiences, Active learning. (Standards: 1, 3, 7, 8).

INTRODUCTION

Biomedical engineering (BME) is aimed at the application of engineering principles, methods and design concepts to medicine and biology for healthcare purposes, mainly as a support for preventive, diagnostic or therapeutic tasks, and is directly connected with professional practice in the medical device development sector. Industrial and management engineers, due to their broad education and global view, can significantly contribute to the advances in the biomedical field, especially if they learn some essential biomedical concepts and train specific professional skills during their higher education degrees. Being a recent field of study, with its first Master's Programmes appearing in the US in the late 1950s (Fagette, 1999) – and the first ones in countries such as Spain just dating back three decades-, the teaching-learning approaches to this field have been continuously evolving, as has happened also with the enormous advances in biomedical technologies, during the last decades. According to the Biomedical Engineering Society, biomedical engineers may be called upon in a wide range of capacities: to design instruments, devices and software, to bring together knowledge from many technical sources, to develop new procedures, or to conduct research needed to solve clinical problems (BMES). The aforementioned duties are directly connected to the traditional corpus of Industrial Engineering (in its broadest sense) and, being applied tasks in direct relation with real and complex problems (pathologies) and systems (human body), can potentially be taught and promoted by means of project-based learning CDIO-related approaches (Crawley, 2007), both within Biomedical Engineering programmes, and in more traditional ones. However, very relevant and multifaceted issues, connected with all aspects of Engineering Management, also arise in any real project devoted to the development of real biomedical devices for addressing relevant health concerns. These aspects (project and team management, conflict resolution, quality and safety promotion, prediction of costs and revenues, production organization, management of the supply chain, ethical and professional aspects, among others) are linked to all stages of the CDIO cycle and need to be analyzed in detail for successfully reaching market and patients. Consequently, the collaboration between academic programmes and between professionals with different backgrounds is essential in BME.

In this study we present the coordinated design and implementation of two courses devoted to the biomedical engineering field, namely "Bioengineering Design" and "MedTech", included in the Master's Degree in Industrial Engineering and in the Master's Degree in Engineering Management respectively, both at the ETSI Industriales from Universidad Politecnica de Madrid. These courses follow the framework established by the Industriales Ingenia Initiative, which is completely aligned with the spirit of the International CDIO Initiative, as presented recently (Lumbreras, 2015, 2016) and the "Bioengineering Design" course is adapted from previous experiences (Díaz Lantada, 2014, 2015, 2016) and integrated with the new "MedTech".

THE “INGENIA” INITIATIVE: INTEGRATED PROMOTION OF CDIO AT THE ETSI INDUSTRIALES FROM UNIVERSIDAD POLITÉCNICA DE MADRID

The implementation of Bologna process culminated at the ETSI Industriales from Universidad Politécnica de Madrid with the beginning of the Master’s Degree in Industrial Engineering, in academic year 2014-15. The program was successfully approved in 2014 by the Spanish Agency for Accreditation (ANECA), with the inclusion of a set of subjects based upon the CDIO methodology denominated generally “INGENIA”, an acronym from the Spanish verb “*ingeniar*” (to provide ingenious solutions), also related etymologically in Spanish with the word “*ingeniero*” (engineer).

INGENIA students experience the complete development process of a complex product or system and there are different kinds of course (and projects) within the initiative, covering most of the engineering majors at the ETSI Industriales from Universidad Politécnica de Madrid. Students choose among the different INGENIA subjects (and projects), depending on their personal interests. These INGENIA subjects are compulsory for all students enrolled in the first year of the Master’s Degree in Industrial Engineering at the ETSI Industriales from Universidad Politécnica de Madrid (a two-year program with 120 ECTS –EU credit transfer system– credits after a four-year Grade in Industrial Technologies with 240 ECTS credits). These subjects (with a similar CDIO orientation but offering different topics and projects) are 12 ECTS credits equivalent, which correspond to a student workload between 300 to 360 hours, distributed along two semesters with the following structure: 120 hours of supervised work plus between 180 to 240 hours of personal student work, organised usually in teams. Professor supervised part of the subjects is divided into 30 hours dedicated to adapt basic theoretical knowledge derived from other subjects to those directly related with the project, and a second set of 60 hours is devoted to practical work in the lab, with professor supervised sessions. Students also receive two seminars of 15 hours; one oriented to transversal outcomes, in particular, workshops on teamwork, communication skills and creativity techniques, and the other one about social responsibility issues such as environmental impact, social, political, security, health, etc. These lectures, practical sessions, seminars and workshops, are distributed along the 28 weeks of the two semesters of the first year, resulting in 5 hours per week of lectures or practical sessions in the regular schedule of students. Placing the INGENIA subjects in the first year of a 120 ECTS program is indeed interesting, as additional 12 ECTS are devoted to the final degree thesis normally during the second year. Therefore, at least 20% of the whole Master’s Degree is devoted to project-based learning aimed at the complete development of engineering products and systems. Program structure is detailed in Figure 1 and the integration of CDIO activities can be appreciated (INGENIA subjects -pale blue- and Final Master’s Thesis -pale green-).

Hours/week	THIRD SEMESTER	ECTS
	Final Master's Thesis	6
6	Curricular configuration	9
2	3 specialization subjects (Automation & Electronical,	3
2	Chemical, Electrical, Energetic, Materials,	3
2	Mechanical, Construction, Org.)	3
2	1 subject on Industrial Installations	3
2	1 subject on Industrial Technologies	3

Hours/week	FOURTH SEMESTER	ECTS
	Final Master's Thesis	6
6	Curricular configuration	9
2	3 specialization subjects (Automation & Electronical,	3
2	Chemical, Electrical, Energetic, Materials,	3
2	Mechanical, Construction, Org.)	3
2	1 subject on Industrial Management	3
2	1 subject on Industrial Technologies	3

Hours/week	FIRST SEMESTER	ECTS
4	INGENIA (first part)	6
2	2 subjects on Industrial Management	3
2		3
2	2 subjects on Industrial Installations	3
2		3
2	4 subjects on Industrial Technologies	3
2		3
2		3
2		3

Hours/week	SECOND SEMESTER	ECTS
4	INGENIA (second part)	6
2	2 subjects on Industrial Management	3
2		3
2	2 subjects on Industrial Installations	3
2		3
2	4 subjects on Industrial Technologies	3
2		3
2		3
2		3

Figure 1. Program structure (Master's Degree in Industrial Engineering).
120 ECTS program with at least 20% devotion to project-based learning activities.

In addition, the INGENIA subjects are helping us to complement our competence-based strategy, in accordance with CDIO Standards 1, 3, 7 & 8. Expected outcomes include the promotion of: students' ability to apply knowledge of mathematics, science and engineering, students' ability to design experiments and interpret data, students' ability to design engineering systems and components to meet desired goals, students' ability to communicate effectively and to work in multidisciplinary teams, or students' ability to use modern resources, in accordance with the ABET professional skills our program tries to promote (Shuman, et al. 2005).

Regarding students' assessment, it is important to note that the proposed engineering systems to be developed within INGENIA courses are complex enough to promote positive interdependence between members of the teams, so that each of the members is needed for the overall success and that there is enough workload to let all students work hard and enjoy the experience. Furthermore, individual assessment can be promoted, by complementing the teamwork activities with individual deliveries and by means of public presentations of final results. The evaluation of professional skills counts with the help of *ad hoc* designed evaluation sheets, as part of an integral framework for the promotion of engineering education beyond technical skills, consequence of recent projects (Hernández Bayo, et al., 2014), and in some cases peer-evaluation has been introduced. Thanks to implementing the CDIO approach in these INGENIA courses, students taking part in these formative programmes are living, in many cases for the first time, through the complete development process of real engineering systems and are getting now better prepared for their final theses and for their future professional practice, as students themselves have highlighted.

Next sections describe and analyze the implementation and first experience with our coordinated courses on "Biomedical Engineering Design" (or "Bioengineering Design") and MedTECH, as a relevant examples of success within the INGENIA framework and as a quite singular example of the benefits and potentials of coordinated courses among different academic programmes, which at least in our country is something quite unusual. They are developed upon previous experiences, as the "Bioengineering Design" course was already within the Industriales INGENIA Initiative (Díaz Lantada, 2014, 2015, 2016), but with a radically innovative approach, providing the first example of coordinated complete CDIO experiences within the Industriales INGENIA Initiative and one of the very first examples of project-based learning experiences in the biomedical engineering field with such a broad scope and holistic approach. Some recommendations for successful project-based teaching-learning experiences have been taken into account for their coordinated implementation

(Díaz Lantada, 2013), as well as some guidelines from inspiring CDIO partners (Salerud, 2006, Bermejo, 2016).

COORDINATED DESIGN AND IMPLEMENTATION OF "BIOENGINEERING DESIGN" AND "MEDTECH" COURSES: MAIN RESULTS AND CHALLENGES

According to the mentioned holistic vision of the Biomedical Engineering field we would like our students to acquire, the two courses, namely "Bioengineering Design" and "MedTECH", share some fundamental lessons and common topics along the two semesters, while some specific lessons also help to differentiate according to the different backgrounds and motivations of the students. Those from "Bioengineering Design" take part in the Master's Degree in Industrial Engineering and prefer to deepen in aspects linked to design, simulation and manufacturing technologies, while those from "MedTECH" belong to the Master's Degree in Engineering Management and are more interested in strategic and business aspects, together with topics related to the organization of production and to the supply chain management. In short, both courses go in parallel and share several general lessons, while a 40% of the lessons are devoted to the more specific aspects with the students from different Master's degrees separated. Each team counts with students from both Master's degrees and all students work together and are responsible for the successful conception, design, implementation and operation of an innovative medical device, although the different skills and backgrounds make them share and distribute tasks according to their experiences and expectations. Globally speaking, conceive and design stages are covered during the first semester and implementation and operation stages are covered during the second one. Figure 2 helps to summarize the organization of both courses and to highlight their mutual interaction.

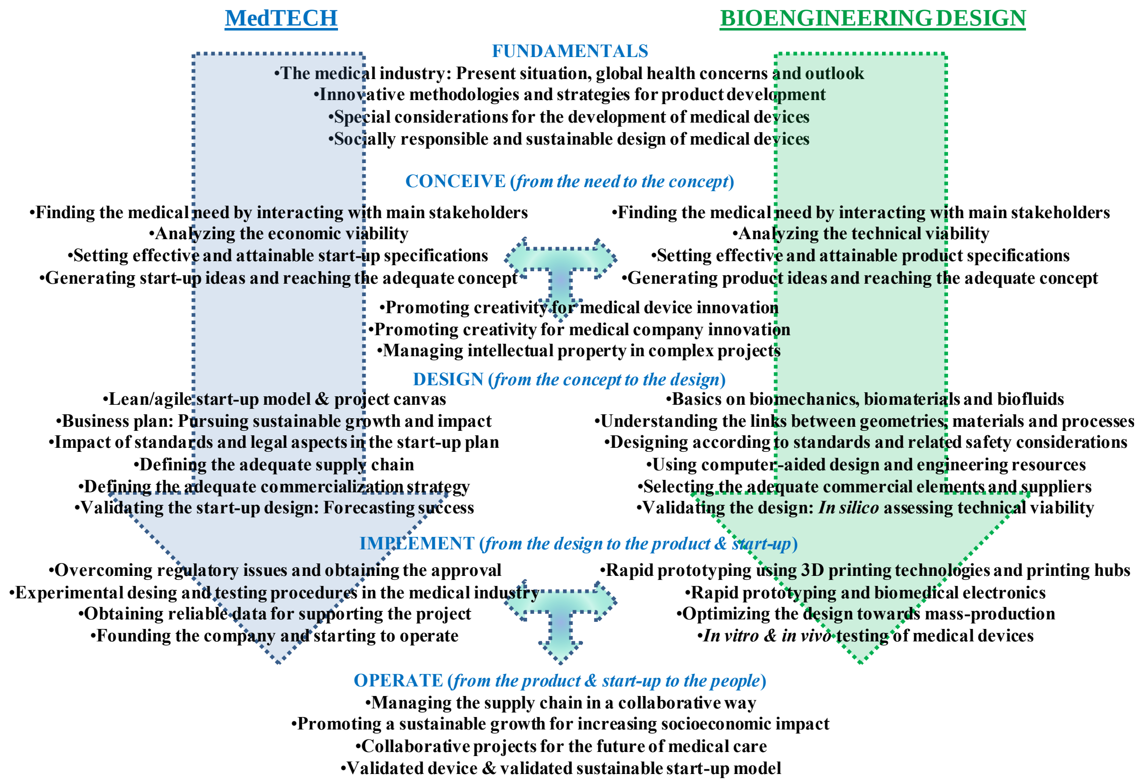

Figure 2. Collaborative scheme among “Bioengineering Design” and “MedTECH”. The topics to the left represent the “MedTECH” track and the topics to the right the “Bioengineering Design” track, while the central topics are common. The fundamentals and conceive and design stages are covered during the first semester, while implementation and operate stages correspond to the second semester.

During the first year with both subjects running in parallel (academic year 2017-2018) a total of 35 students from “Bioengineering Design” –Master’s Degree in Industrial Engineering- and a total of 15 students from “MedTECH” –Master’s Degree in Engineering Management- enrolled in these courses implemented according to the Industriales INGENIA Initiative, each counting with 12 ECTS, which corresponds to a total dedication of around 300 hours of student personal dedication (including lessons and work outside the classroom in laboratories, at home and devoted to teamwork). At the beginning of the course, students were divided into 6 teams of around 8 students and each team counts with components of the different involved degrees and, consequently, of different backgrounds, so as to better fulfill the expectations regarding the whole CDIO cycle with the selected medical devices. Each team proposed several medical needs and related potential biodevices to be developed and, after a voting session, 6 different ideas were distributed among the different teams, including: a sensorized vest for detecting and alerting about fallen patients, a sensorized t-shirt for detecting wrong positions during working, an instrumented pill dispenser, an ergonomic aid for applying droplets to the eyes, a use-and-throw amnioscope, an a system for training injured hands. At the current state of development, student groups have already completed their product specification and conceptual designs (according to the images shown as examples in Figure 3) and the final devices are being prototyped and tested (Figure 4). These designs and prototypes have been supported by specific focus on marketing & promotion (Figure 5), market assessment, approach to open-innovation platforms, contact with medical professionals and associations, under the responsibility of the students from Engineering Management acting as “project leaders”.

In our opinion, the multidisciplinarity of the teams is leading to very interesting results, with much more professional devices than those from previous experiences (Díaz Lantada, 2015, 2016), as will be presented, together with data from the assessment, during the 14th International CDIO Conference of Kanazawa. In addition, according to preliminary evaluations, student and professor motivation has been importantly promoted thanks to the collaborative approach. Students from different backgrounds have really worked as coordinated teams and individualization of assessment has been promoted thanks to public presentations, individual deliverables and proactive performance in and out of class, which account for a 20% of global qualification, as support to main assessment (80%) based on projects’ results.

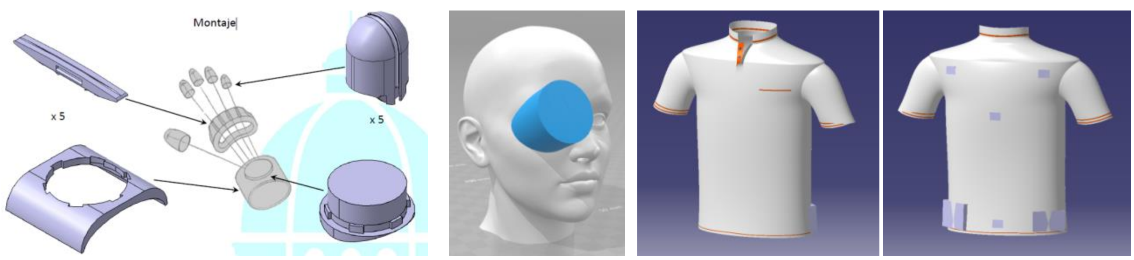

Figure 3. Some examples of the proposed concepts and designs. a) Hand trainer. b) Ergonomic eye-droplet supplier. c) Sensorized vest for ergonomic assistance.

Figure 4. Some examples of the final prototypes and tests.
a) Assessment of tolerances for pill dispenser. b) Sensor encapsulation in PDMS.

Figure 5. Examples of commercial flyers after market segmentation analyses:
a) Hand training device and b) low-cost amnioscope for mass production.

CONCLUSIONS

In this study we have presented the coordinated design and implementation of two courses devoted to the biomedical engineering field, namely “Bioengineering Design” and “MedTech”, included in the Master’s Degree in Industrial Engineering and in the Master’s Degree in Engineering Management respectively, both given at the ETSI Industriales from Universidad Politecnica de Madrid. These courses are following the framework established by the Industriales Ingenia Initiative, which is completely aligned with the spirit of the International CDIO Initiative and constitute a source of motivation, both for students and professors, who see their scientific-technological background applied to solving real problems. During this first coordinated implementation, students are benefiting from a more global point of view, in connection with the biomedical engineering field and with the engineering design of biomedical devices, taking also account of the existing regulatory framework and of relevant socio-economic issues, which condition the technical decisions. The results obtained so far motivate us to continue with this coordinated and more holistic approach, which will let us hopefully reach medical professionals and patients for improved social impacts in the near future.

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BIOGRAPHICAL INFORMATION

Andrés Díaz Lantada is Professor in the Department of Mechanical Engineering at ETSI Industriales – UPM. His research activities are aimed at the development of biodevices using modern design, modeling and manufacturing technologies and he incorporates these results to subjects linked to product development. He is Editorial Board Member of the International Journal of Engineering Education and CDIO contact at UPM. He has received the "TU Madrid Young Researcher Award" and the "TU Madrid Teaching Innovation Award" in 2014 and the "Medal of the Spanish Academy of Engineering to Young Researchers" in 2015.

Luis Ignacio Ballesteros Sánchez is Professor in the Department of Industrial Management, Business Administration and Statistics at ETSI Industriales – UPM. He is focused on systematic project management procedures and on the resolution of conflicts in multidisciplinary teams, hence supporting both courses and mentoring the adequate progress of the different teams.

Enrique Chacón Tanarro is Professor in the Department of Mechanical Engineering at ETSI Industriales – UPM. His research activities are linked to several fields of Mechanical Engineering, including most areas of tribology and contact phenomena, machine performance assessment and systematic product development.

Ana Moreno Romero is Professor in the Department of Industrial Management, Business Administration and Statistics at ETSI Industriales – UPM. She is currently Deputy Vice-Dean for Social Responsibility and is especially focused on the management of change in complex organizations and on professional development.

Rafael Borge García is Professor in the Department of Chemical Engineering at ETSI Industriales – UPM. He is our expert on sustainable engineering design and supports both courses with the systematic assessment of products' life-cycles for enhanced selection and definition of geometries, materials and processes.

Miguel Ángel Peláez García is Professor in the Department of Industrial Management, Business Administration and Statistics at ETSI Industriales – UPM. He supports these subjects by means of his expertise in medical device regulation towards optimized marketability processes.

Rafael Ramos Díaz is Professor in the Department of Industrial Management, Business Administration and Statistics at ETSI Industriales – UPM. He supports both courses with innovative approaches to entrepreneurship.

Jesús Juan Ruíz is Professor in the Department of Industrial Management, Business Administration and Statistics at ETSI Industriales – UPM. He supports both course with experimental design expertise and statistical validation of implementation and operation results, coordinating also the Management Engineering track.

Corresponding author

Prof. Dr. Andrés Díaz Lantada
Mechanical Engineering Department,
Universidad Politécnica de Madrid
c/ Jose Gutierrez Abascal 2,
28006 Madrid, Spain
adiaz@etsii.upm.es

THE "UBORA" DESIGN COMPETITION: AN INTERNATIONAL STUDENT CHALLENGE FOCUSED ON INNOVATIVE MEDICAL DEVICES DEVELOPED USING THE "CDIO" METHODOLOGY

Arti Ahluwalia[1], Carmelo De Maria[1], Andrés Díaz Lantada[2]*, Licia Di Pietro[1], Alice Ravizza[1], Mannan Mridha[3], Philippa Ngaju Makobore[4], June Madete[5], Janno Torop[6]

[1]University of Pisa, [2]Universidad Politécnica de Madrid, [3]Kungliga Tekniska Högskolan, [4]Uganda Industrial Research Institute, [5]Kenyatta University, [6]Tartu Ulikool
*Contact: adiaz@etsii.upm.es

ABSTRACT

UBORA is an educational and design online platform or infrastructure aimed at the collaborative development of open-source medical devices (OSMD) to address current and future global healthcare challenges. It pretends to support the healthcare professionals and the medical industry with new methods for creation of innovative solutions that take into account needs, safety, feasibility, efficacy and performance. To support the implementation and testing of the UBORA e-infrastructure and to promote the future impact of OSMD, teaching-learning actuations play a fundamental role. In consequence, in parallel to the implementation of the mentioned infrastructure, a set of international design competitions and schools are being developed. In this study we present the results from the "First UBORA Design Competition".

This "First UBORA Design Competition" counted with a total of 113 submitted projects, from which 60 were selected for a second round. After such second round, 26 especially relevant projects and their teams, which lived in many cases a complete CDIO experience, have been assessed and chosen as finalists. Among presented projects and solutions we can cite: medical devices for detecting or preventing malaria, portable vaccine coolers, systems for the sterilization of medical and instruments, incubators for newborns, devices for monitoring pregnancy, breast pumps with cooling and preservation systems, 4D printed ergonomic supports, polymeric devices for treating articular pathologies and CPAP devices for babies, to mention just a few examples. Most of the finalist teams have reached the prototyping and testing stage, following the recommendations provided by the organizers of the competition and by the participating mentors, in order to better answer the questions from the two-stage evaluation sheets, which serve as a sort of "lean canvas" or creativity promotion templates to guide the development process. The first stage of the competition mainly covered the conceptual stage and the second stage focused on the design, implementation and operation of the obtained prototypes. The international magnitude of the competition can be appreciated by taking into account that teams from 15 universities and 12 countries from Europe and Africa took part in this first edition. Main benefits, lessons learned and future challenges, linked to these international medical device design competitions, are analyzed,

taking account of the available results from this first implementation during 2017, so as to improve towards the future editions.

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KEYWORDS

CDIO implementation, Case studies & best practices, Integrated learning experiences, Active learning. (Standards: 1, 3, 7, 8).

INTRODUCTION

Student competitions can constitute excellent teaching-learning experiences because they tend to promote student motivation, which is arguably the most relevant key to success in Engineering Education. In many cases competitions serve to approach students to their professional practice, let them apply basic scientific-technological knowledge to real life problems, promote their teamwork and communication skills and even involve them in multi-cultural international contexts, while letting them escape from their routine for some hours or days, which is always beneficial.

However, there are relevant challenges linked to the implementation of really formative student competitions and connected with their long-term sustainability. First of all, in many cases competitions are organized by students themselves or by student associations, which normally limits their temporal sustainability due to the short life-cycle of many student associations. Apart from that, students do not usually focus on the development of adequate assessment methods for their competitions, as objective procedures are not so easy to implement. Secondly, in other cases, competitions are organized by enterprises looking for innovative solutions for their own interests or as a way of finding or attracting talent, which again can limit their sustainability, as the entrepreneurial objectives can vary easily in the short-term. In these cases, assessment is usually not performed in ideal conditions either, as these entrepreneurial competitions are typically overviewed by the human resources departments, whose understanding about engineering (and teaching) is not always as desired. Finally, student competitions are normally performed as extra-curricular activities, with no connection to the plans of study and with no intention of becoming part of these plans either, which leads sometimes to curricular and temporal mismatches (i.e. competitions organized in exams period, topics without interest for the participants…).

Counting with the active support of professors for the conception, implementation and evaluation of student competitions can prove very positive for adding value to the formative and transformative potential of student competitions, as connected with the enhancement of teaching-learning objectives, with the performance of an adequate evaluation and with the search for a long-term sustainability, possibly connected with the consideration of these contests as curricular activities. Applying the CDIO approach (Crawley, 2007 & CDIO Standards) to student contests, letting students live through complete conceive-design-implement-operate cycles linked to real engineering systems, can constitute also a relevant driver of change. Some exemplary proposals have been able to create long-term and international competition schemes with students living complete CDIO cycles, in which engineering systems as complex as competition cars and solar houses have been implemented: The Formula SAE (running since 1980) and the Solar Decathlon (starting in 2002) are some of the more relevant examples of student competitions, which started with the support of US universities or US governmental departments, counting with relevant involvement of professors since the beginning, and are now truly international events. The engineering systems developed within these competitions are complex and provide students with holistic engineering design experiences. Other engineering systems common from engineering design competitions include: motorbikes, drones, ultra light planes, among others.

In our case, conscious about the relevance of equitable medical technology for the future of global health coverage and compromised with the development and teaching of open-source approaches for the development of biomedical products (De Maria, 2014, 2015), we have conceived and developed an international student competition focused on the complete development of innovative medical devices, which is presented in this study.

THE “UBORA” PROJECT

The EU funded UBORA project (*H2020-INFRASUPP-2016-2017 call: Support to policy and international cooperation*) aims at creating an e-Infrastructure, UBORA, for open source co-design of new solutions to face the current and future healthcare challenges of Europe and Africa, by exploiting networking, knowledge on rapid prototyping of new ideas and sharing of safety criteria and performance data. The e-Infrastructure is being implemented to foster advances in education and the development of innovative solutions in Biomedical Engineering, both of which are flywheels for emerging and developed economies. It is conceived as a virtual platform for generating, exchanging, improving and implementing creative ideas in Biomedical Engineering underpinned by a solid safety assessment framework. Besides the provision of resources with designs, blueprints and support on safety assessment and harmonization, specific sections for needs identification, project management, repositories and fund raising are also foreseen.

UBORA (“excellence” in Swahili) brings together European and African Universities and their associated technological hubs (supporting biomedical prototyping laboratories and incubators), national and international policymakers and committed and credible stakeholders propelled by a series of summer schools and competitions (Ahluwalia, 2017). Through the UBORA e-Infrastructure, the biomedical community can generate and share open data and blueprints of biomedical devices, accompanied by the required procedures for respecting quality assurance, and assessing performance and safety. When properly implemented, as guaranteed by authorized Notified Bodies, these biomedical devices can safely be used in hospitals and on patients. In a nutshell, UBORA couples the open design philosophy with Europe’s leadership in quality control and safety assurance, guaranteeing better health and new opportunities for growth and innovation.

The teaching-learning experiences within the UBORA project, mainly summer schools and competitions, are being implemented on the basis of the CDIO (conceive-design-implement-operate) principles linking European and African students sharing the complete development process of innovative medical devices for global health concerns. Such collaborative open design teaching-learning experiences are expected to promote and rethink Biomedical Engineering Education across Europe, Africa and throughout the globe, while also serving as main initial input for making the UBORA e-Infrastructure become a key resource for the future of personalized and universal healthcare.

We believe that the approach is quite innovative, especially regarding the open-access strategy and the collaborative design approach, all of which, when connected with the CDIO methodology, may prove a relevant breakthrough in the Biomedical Engineering and Biomedical Education fields.

In this work, we present the results from the first UBORA Design Competition (2017), which is also the first in a series of international biomedical device design competitions focusing on open innovation and collaborative design approaches and devoted to the conception, design, implementation and operation of biomedical devices. In turn, these UBORA Design Competitions give access to the UBORA Design Schools, as one member per finalist team of these design competitions receives funding to attend the mentioned UBORA Design Schools (also presented in this 14^{th} International CDIO Conference of Kanazawa). The teaching-learning objectives of the competition, its development stages, the main results of the first implementation and the more relevant future challenges are presented in the following pages.

ENGINEERING COMPETITION FOLLOWING A COMPLETE "CDIO" CYCLE: THE FIRST "UBORA" BIOMEDICAL DEVICE DESIGN COMPETITION

Objectives

The main objective of the UBORA Design Competitions was letting groups of students live through a complete CDIO process, linked to the development of innovative biomedical devices and performed in two stages, one for presenting the idea and one for focusing on design and prototyping aspects. Making them aware of the relevance of engineers for improving society and involving them in an international context in connection with relevant health issues, in accordance with Part 4 of the CDIO Syllabus, were also desired outcomes. The stages of the competition let students face relevant challenges typical from the biomedical industry, including: the finding of a socially relevant medical need, the specification of a biomedical device for solving such medical need, the analysis of existing solutions, the selection of medical device class or the development of a design oriented to production. For supporting students and gathering the necessary information to assess participants of the competition, two working sheets with different sections were implemented, one as final deliverable of the first stage and one as final deliverable of the second stage. These evaluation sheets served as a sort of "lean canvas" or creativity promotion templates to guide the development process. It is important to note that the topic of this first UBORA Design Competition was child and maternal health and that the final award for each finalist team was a travel fellowship, for one team member, to attend the first UBORA Design School of 2017.

First stage

The first UBORA Design competition was launched at the beginning of 2017 and open to bachelor's and master's degree students from the institutions of the UBORA consortium (University of Pisa, Universidad Politécnica de Madrid, KTH, Kenyatta University, UIRI and University of Tartu) and from the African Biomedical Engineering Consortium (ABEC). A total of 15 institutions from 12 countries across Europe and Africa were called for participation. During the first stage we received 113 submissions, which conceptually described medical devices for solving relevant medical issues, also analyzing their potential impacts socio-economic impacts. Figure 1 shows some of the filled in templates received, which contain the basic information of the conceptual stage. A total of 60 teams were selected for the second round, assessed on the basis of: heath impact (5 points) and innovation (5 points). Aspects including the focus on child mortality, the addressing of the health need, the demonstration of potential impact, the proposal of creative solution, the rationale for the unique approach and a search for cost efficient technical were considered (see http://ubora-biomedical.org).

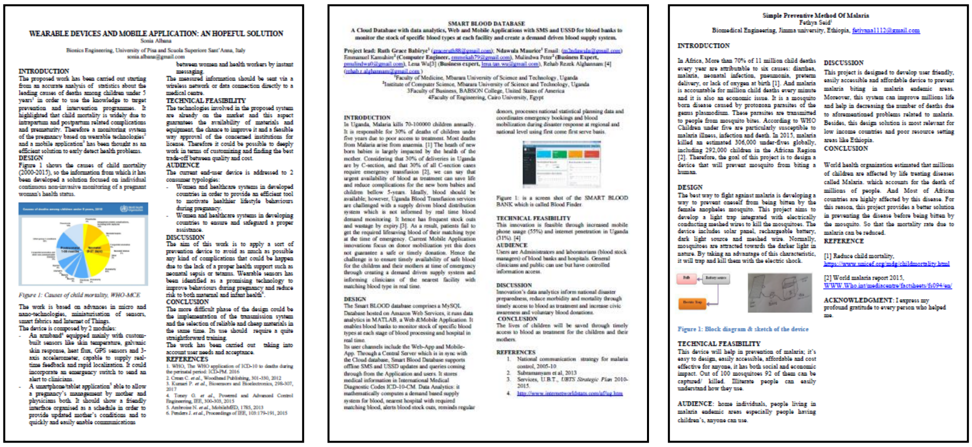


Figure 1. Examples of first stage submission documents: Abstracts describing the medical need and common issues, together with the proposed medical device concept.

Second stage

During the second stage 60 complete submissions were received, from which a total of 26 finalist teams was selected. The templates used to gather the required information during the first and second stages can be found at: http://ubora-biomedical.org. The second stage focused on more specific design, production and supply chain related aspects, including analyses on how to reach local populations in remote places or even involve them in the development or personalization processes. Figure 2 shows some examples of implemented prototypes during this second stage, which was evaluated again according to health impact and innovation, but taking also into account the degree of completion of the whole CDIO cycle achieved by the teams.

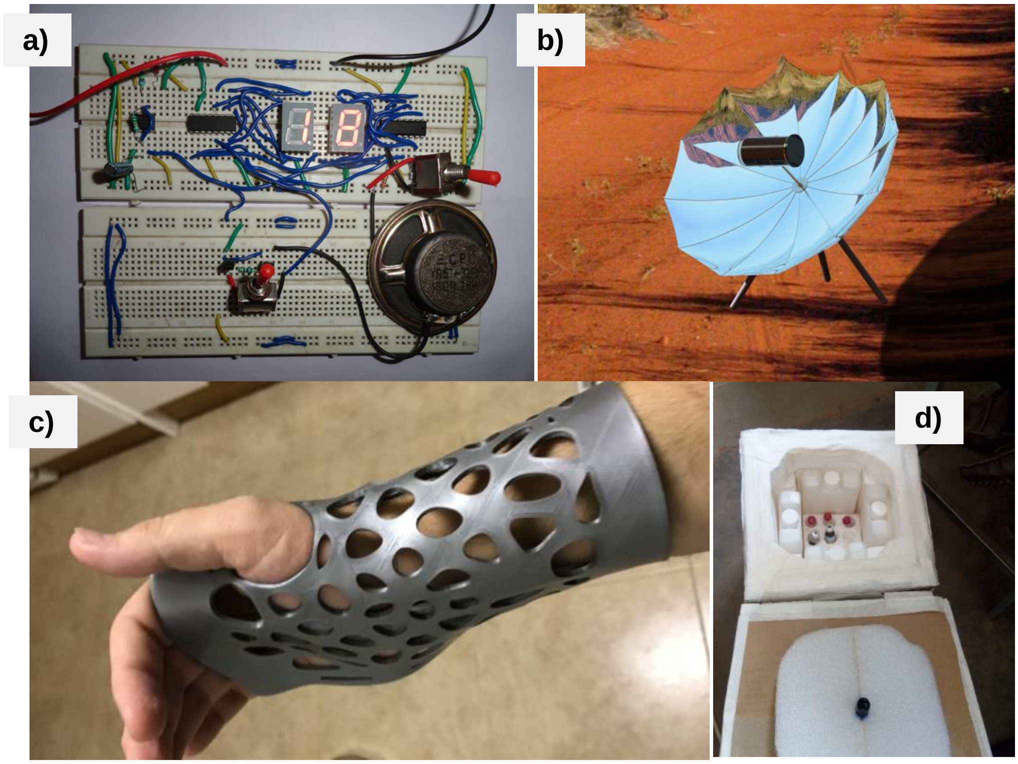
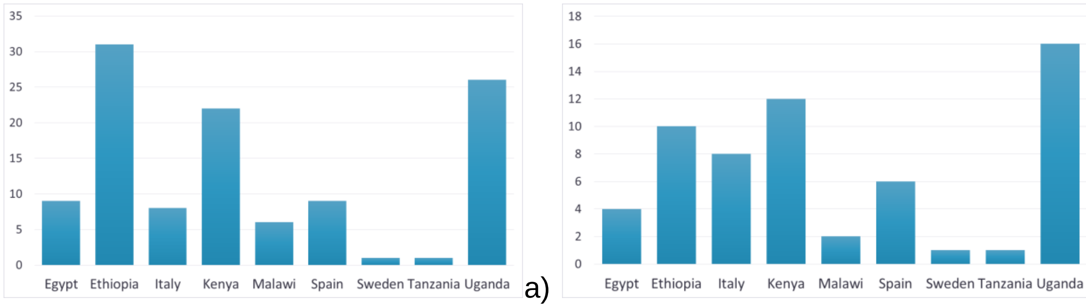


Figure 2. Examples of implemented prototypes during the second stage of the competition: a) Electronic board for monitoring baby temperature (with audio alert).
b) Low-cost solar autoclave. c) 4D printed splint for articular pathologies.
d) Vaccine cooler with temperature sensor for improved traceability of the cold chain.

Main results and future challenges

CDIO approach was supported by means of guiding documents, which helped students to specify and describe their concepts, in the first stage, and to address relevant engineering aspects and present their final solutions, in the second stage. Professors from the involved institutions acted as supporting mentors, either *in situ* or by means of online interactions. Regarding participation, a total of 113 projects from undergraduate student teams from 10 ABEC and 4 UBORA universities were received (Figure 3a). Overall, we had 334 students, 253 from ABEC and 81 from UBORA member institutions. Sixty (60) projects were selected for the second round. After the first stage review, 57 projects were submitted (Figure 3b) and of these, the first 26 were selected as winners. A total of 191 students participated (133 from ABEC, 58 from UBORA). One student from each team received funding for travel and accommodation to participate in the Design School (see our partner document presented also at the 14th International CDIO Conference about the UBORA Design School).



b)

Figure 3. Number of projects submitted per country in the first (a) and second stage (b).

Among the biomedical devices presented, all of which were centered on infant and child mortality and health we can cite: medical devices for detecting or preventing malaria, portable vaccine coolers, systems for the sterilization of medical and instruments, incubators for newborns, devices for monitoring pregnancy, breast pumps with milk cooling systems, 4D printed ergonomic supports, polymeric devices for articular pathologies and CPAP devices for babies, devices for filtering water, to mention just a few examples. All of the finalist teams addressed relevant health concerns and provided innovative concepts and basic designs. Most of the finalist teams reached a basic prototyping and testing stage, following the recommendations provided by the organizers of the competition, in order to better answer the questions from the two-stage evaluation sheets and to validate their concepts and designs. At least one member of each finalist team attended the first UBORA Design School of Nairobi (December 2017), in accordance with the received awards, which constitutes a very special selection for such design schools based on merit.

The experience resulted satisfactory both for students and teachers, as can be seen from their active involvement as members of the UBORA community after the end of the competition (). Currently the second UBORA Design Competition is being performed, which will end with a selection of participants for the second UBORA Design School (to be performed in Pisa, in September 2018). Regarding future challenges, we would like to focus on the sustainability of these international teaching-learning activities and to see them become part of worldwide actuations linked to establishing a new generation of biomedical engineers focusing on open-source approaches towards equitable access to medical technologies. Finding sponsors and linking these actuations with curricular activities of plans of study of the participant universities may be fundamental, as happens also with the potential incorporation of our partners to the international CDIO initiative.

CONCLUSIONS

We have presented the implementation process and main results of the first UBORA Design Competition, an international contest, with participation of students from the partners of the UBORA and ABEC consortia, in which teams of students live through the complete development process of innovative medical devices. These developments have followed the CDIO approach and have been implemented in two phases, one linked to the more conceptual aspects, the second one connected to design and prototyping activities. A total of 113 teams from 12 European and African countries and 15 universities have taken place in this competition and a total of 24 finalist teams have been granted access to the first UBORA Design School, a complete CDIO experience linked to biomedical devices in just one week, which is also presented in this 14th International CDIO Conference. To our knowledge, this competition provides one of the very first examples of CDIO-related contests applied to medical technology worldwide.

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SAE Formula Competition: https://www.fsaeonline.com

Solar Decathlon Competition: https://www.solardecathlon.gov

United Nations. Sustainable Development Goals: 17 Goals to transform our World:

http://www.un.org/sustainabledevelopment/sustainable-development-goals/

Regarding the UBORA Project, additional information and developments can be found at:

UBORA Project: http://ubora-biomedical.org

UBORA e-Infrastructure: http://ubora-kahawa.azurewebsites.net (preliminar versión).

Second UBORA Design Competition: http://ubora-biomedical.org/design-competition-2018/

BIOGRAPHICAL INFORMATION

Arti Ahluwalia is Professor of Bioengineering at the Department of Ingegneria dell' Informazione, University of Pisa, and affiliated with the Research Center "E. Piaggio", where she is head of the IVM Group (www.centropiaggio.unipi.it). Prof Ahluwalia is also an associate of the National Council of Research Institute of Clinical Physiology (CNR-IFC), and head of the NanoBioscopy Lab. She has several papers published in international scientific journals (over 100) and is author of 13 patents on microfabrication, and on micro-fabricated multi-compartmental bioreactors. She is co-founder of two hi-tec companies and 5 of her patents have been industrialized to date. She coordinated an EU-Asialink project on the development of human resources in biomedical engineering in South East Asia. She has pioneered Open Education in Biomedical Engineering in Africa and is a Scientific and Education Consultant for Biomedical Engineering for the United Nations Economic Commission for Africa. She was instrumental in setting up the African Biomedical Engineering Consortium and is the consortium's patron, and the coordinator of the UBORA EU project.

Carmelo De Maria is Assistant Professor of Bioengineering at the Department of Ingegneria dell' Informazione, University of Pisa, and affiliated with the Research Center "E. Piaggio". He is guest professor in bioengineering at Addis Ababa University, and member of the African Biomedical Engineering Consortium secretariat. His research interests are in the field of additive manufacturing, with a particular focus in biofabrication. He has several papers published in international scientific journals (over 30) and in 2016 he received the 1st award as Young Investigator from the International Society for Biofabrication. De Maria is co-founder and president of the FabLab Pisa.

Andrés Díaz Lantada is Professor in the Department of Mechanical Engineering at ETSI Industriales – UPM. His research activities are aimed at the development of biodevices using modern design and manufacturing technologies. He is Editorial Board Member of the International Journal of Engineering Education and CDIO contact at UPM. He has received the "TU Madrid Young Researcher Award" and the "TU Madrid Teaching Innovation Award" in 2014 and the "Medal of the Spanish Academy of Engineering to Young Researchers" in 2015.

Licia Di Pietro is a PhD Biomedical Engineering Student at Research Centre E. Piaggio of University of Pisa, Italy. She received the Bachelor's and Master's Degrees in Biomedical Engineering from University of Pisa in 2014 and 2017 respectively. Her research interests include Global Health with particular attention to developing countries. She is working on manufacturing of open-source and low cost medical devices, compliant with the international standards.

Alice Ravizza is regulatory consultant and R&D reviewer for medical devices, expert in implementation of Good Manufacturing Procedure and Quality Management System (ISO 13485). Dr. Ravizza is involved in several CE marking processes linked to class I, II and III medical devices. She performs courses on medical regulation and supports the UBORA project with her expertise in safety and quality promotion.

Mannan Mridha is a Senior Researcher at KTH (Royal Institute of Technology) in Stockholm. With merit scholarships acquired M.Sc. Eng. degree from Warsaw Technical University, Ph.D. and M.Ed. degree from Linköping University in Sweden. He has working experience with teaching and research in BME at the University of Linköping, KTH, University of Oxford and

Tokyo University. He strongly believes in the importance of preventive health care through education utilizing the digital technology.

Philippa Ngaju Makobore is an Electrical Engineer and is currently the Department Head of the Instrumentation Division at the Uganda Industrial Research Institute. Her multidisciplinary team designs and develops electronic applications for Healthcare, Agriculture and Energy. To date the Division's portfolio has over 7 projects, which she supervises. These projects have won several awards including a 1st place Innovation Award at the 2016 World Patient Safety, Science and Technology Summit.

June Madete is a Biomedical Engineer specializing in biomechanics, a researcher and senior lecturer at Kenyatta University with special interest and expertise in analysis and interpretation of gait data using various analysis software and hardware. Her research involves combination of these techniques with animal research in the field of video fluoroscopy, X-ray and CT data. She seeks to develop biomechanics within Kenya.

Janno Torop works at the Institute of Technology at the University of Tartu developing research in the field of Materials Chemistry and Nanotechnology, in connection with the development of smart materials, structures and actuators. He supports UBORA as mentor of project-based learning activities and as developer of biomedical devices.

Corresponding author

Prof. Dr. Andrés Díaz Lantada
Mechanical Engineering Department,
Universidad Politécnica de Madrid
c/ Jose Gutierrez Abascal 2,
28006 Madrid, Spain
adiaz@etsii.upm.es

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COMBINING CDIO AND CASE STUDY METHODOLOGIES IN FLIPPED CLASSROOM STRATEGIES

Juan M. Munoz-Guijosa, E. Chacón, J. Echávarri, A. Díaz, A. Guzmán, J. De la Peña García de la Tenaza

Universidad Politécnica de Madrid – Mechanical Engineering Department

ABSTRACT

Case Study methodology has been successfully applied in many teaching areas, as business administration, economics, law or medicine, where the implementation and operation of different solution alternatives is risky and/or expensive. It is an excellent tool for allowing students to experience real life problems, with no explicit questions and subjected to multidisciplinary restraints, letting them theoretically test different solutions through the teacher assistance. Furthermore, student activities associated to this teaching methodology (teamwork, creativity, multidisciplinary work, self-learning, class participation, presentations, etc.) greatly foster the acquisition of transversal competences, which can be enhanced through the simultaneous use of other teaching strategies as flipped classroom or gamification. A clear parallelism between the learning objectives and outcomes can be observed between case study and CDIO teaching methodologies. However, case studies usually focus on the “C”, “D” and sometimes “I” phases, rarely executing the “O” phase because of the reasons described above.

We think that case study methodology can be fully (that is, including the “O” phase) and successfully applied as component of the CDIO methodology for the teaching of specific engineering concepts and methodologies, improving the teaching outcomes reached by the students, especially those related to the acquisition of theoretical knowledge and methodologies. The use of rapid prototyping techniques allowing to develop demonstrators, in combination with the development of additional teaching and learning resources, as online tests, non-supervised study documentation, teaching guides and case texts, allows for the full integration of the case study and CDIO methodologies, taking also advantage of flipped classroom techniques, which in turn allocates more time for the discussion of alternatives in class, by transferring the teaching of theoretical concepts to out of class student activities.

We have tested this hypothesis in our “Machine Element Design” and “Vibrations in Machinery” courses. In this work, we will describe the full methodology, give examples of the demonstrators and teaching resources developed, and describe our particular thoughts about the implementation and outcomes of this combined methodology.

KEYWORDS

Case study, flipped classroom, rapid prototyping, mechanical engineering, standards: 7, 8, 10.

INTRODUCTION

In fields as computer science or electronics, the huge advances carried out during the last decades have given rise to powerful standard solutions, systems and components, with very low cost and size, and manufactured in enormous volumes. In mechanical engineering, however, the components handled have sizes, weights and costs several orders of magnitude bigger. This forces mechanical engineers to optimize weight and costs. Furthermore, due to a substantially lower level of standardization, several working principles are usually available for the same problem, which forces to complex decision making processes based on the evaluation of alternatives as a function of parameters associated to product lifecycle and the particular problem restraints. In addition, and due also to the lower standardization level, working principles must be adapted to the particular problem, which also means a complex design exercise. All the aforementioned environment implies the continuous use of creativity, problem solving, teamwork, lifelong self-learning and continuous improvement skills, which must consequently be cultivated in the mechanical engineering students.

In our experience teaching different full-course CDIO graduate subjects as “Engineering Design” or “Bioengineering” (Munoz-Guijosa 2016), (Chacón 2015), (Díaz 2013), we have realized that students, normally coming from an Industrial Technologies Engineering degree, show deep theoretical knowledge about mechanics, physics, electrical engineering and electronics. However, they are not so skilled in the application of those theoretical knowledge to real life design problems which imply a global view of the machine, as materials selection, mechanical couplings design, estimation of complex stress states, combination of different energy fields, or application of dynamic design criteria as fatigue, manufacturability, ergonomics or safety.

In our opinion, case study methodology may be a potentially effective tool to mitigate this weakness. The application of this methodology in specialized undergraduate and graduate subjects as “Machine Elements Design”, “Machinery Vibrations” or “Tribology” allows for a reduction of the time devoted to lectures by letting the student self-learn the theoretical knowledge. The available class time is then used for the application of problem solving methodologies in the mechanical design.

Usually, case studies are employed in medicine, law or business education (Edenhammar 2017) (Tripathy 2009) (Jain 2005). A problematic situation is deeply, quantitatively and precisely described, and a solution proposal -arising from the evaluation of different alternatives- as well as an implementation strategy are requested to the students. Obviously, implementation and operation of different solution alternatives is risky and/or expensive in the aforementioned fields, so case studies typically focus on the “C”, “D” and “I” stages of the CDIO process, rarely achieving the “O” one.

The Case Study Method has already been implemented in Engineering courses and Mechanical Engineering courses specifically. Whereas some authors (Runeson and Höst, 2009) put their focus on the actual implementation and creation of engaging and knowledge-wise rich Cases of Study as well as their correct assessment regarding individual and team-based skills; others (Yadav et al., 2010) have evaluated the actual impact of this methodology on Mechanical Engineering undergraduate students. The results of this implementation clearly show that students undergoing Case Study methodologies presented a higher level of attention and engagement on the problem posed while retaining the same level of understanding versus students following a classical lecture-based approach. Nonetheless, the benefits of the Case Study Method include, but not limit to the aforementioned perks. Authors (Raju and Sankar, 1999) have reported that students highly preferred a Case Study Method-based course than a traditional lecture-based, as they helped them develop their communication assets and gave them an option to apply the knowledge learned in the course. However, this methodology lacks in laboratory experiences and field work from the students, so the conclusions about the use of the case study methodology are similar to those arisen in law, medicine or business education.

However, the use of rapid prototyping technologies may allow for the execution of the “O” phase due to the substantial cost and time reduction achievable in the manufacturing of simple test benches, test coupons or mechanisms. For instance, machinery elements as springs or couplings can be rapidly obtained after a design phase, so a testing procedure can be performed in class. Similar exercises can be carried out with friction bearings or rotating disks. The successful use of case study methodologies integrated in a CDIO process could then achieve the double goal of maximizing the theoretical knowledge acquisition as well as developing the specified professional skills. Furthermore, if correctly designed, case studies can be used in different subjects by simply focusing the problem in a different way. The use of case study methodologies implies also an important teacher activity, which can trigger substantial improvements in his/her teaching style and qualify for a better teaching of full-course CDIO subjects. The CDIO standards provide a methodology foundation to be complemented with other assessment instruments. This CDIO methodology approach, combined with Case Study Method and rapid prototyping technologies, may provide the student the laboratory experience, field work and manufacturing know-how required to excel at Mechanical and Machinery Design.

REQUISITES FOR THE INTEGRATION OF CDIO AND CASE STUDY METHODOLOGIES FOR THE TEACHING OF SPECIFIC KNOWLEDGES IN TIME-RESTRAINED MECHANICAL ENGINEERING COURSES

Mechanical engineering graduate and undergraduate specialization courses have some particularities, which should be observed in order to design good case study based resources. Firstly, numerous different concepts, based on a substantially hard theoretical body of knowledge must be taught in each subject. For instance, “Machinery Vibrations” is composed of 17 sections, covering from Fourier Transform basics to vibrations in nonlinear systems and numerical methods for vibrations. “Machinery Elements Design” covers the knowledge needed for the design of a vast variety of elements, from brakes to clutches, chain-sprocket systems, or epicyclical gear trains. Whereas the acquisition of the theoretical body of knowledge must be ensured, a wide, problem solving skillset is also expected to be acquired by students. This is difficult due to the limited time available (typically 4 to 6 ECTS). The implementation of an effective case study methodology must ensure the fulfillment of both goals simultaneously. Consequently, in order to establish a methodology that can be successfully applied in practice, following considerations should be taken into account:

Need of implementation of a previously defined solution

The main goal of a full CDIO subject is the acquisition of the planned hard and professional skills through the living of a complete design experience. This does not mean that the final design level reached is the one initially planned by teachers or industry experts, with a considerable experience in design. Despite we do not have quantitative evidences about -yet-, we have realized in our 5 years of experience teaching CDIO courses that the acquisition of the desired skills is uncoupled with the design level finally reached. Excessive teacher interference in the students' work related to design improvement proposals frequently reduces the student intellectual activity, mainly related to analysis, creativity and working principles selection, and consequently also reduces the level of acquisition of the desired skills. Errors are excellent triggers for learning and skills acquisition. Obviously, teachers must maximize the acquisition of the desired skills by allowing errors, but simultaneously must minimize the associated economical cost. In a full CDIO subject, usually with a 12 ECTS (full course) size, this strategy can be executed if teachers have enough experience. However, for teaching specialized knowledge in shorter mechanical design courses (usually 4 to 6 ECTS), where numerous, different issues must be addressed, and certain time is assigned in advance to each of them, the aforementioned strategy cannot be applied. If a CDIO methodology is desired for teaching such kind of specialized knowledge, a well-defined design goal must be established, to which students can be guided by the teachers.

Need of teachers skilled in innovative teaching methodologies

For a successful application of the CDIO or case study methodologies, teachers must be able to control unexpected class situations, associated to the confrontation to an open question, where multiple solutions exist. Teachers must also be able to guide the class to that solution previously planned, minimizing the interference with the students intellectual activity. This implies a proficiency in interpersonal skills, as well as previous experience in complete CDIO courses. Additional resources must be created if teachers lack of these characteristics.

Need of avoiding student specialization due to work-sharing

In full CDIO subjects, where complex, multidisciplinary, open problems are faced, groups of 6-8 students are usually formed. Due to the problem complexity, students spontaneously organize, defining work packages and distributing them across the team. While this specialization is advantageous in full CDIO subjects, it may not be desired in shorter subjects where very specific concepts or methodologies are expected to be acquired by all the students.

Need for the planning of the student out-of-class activity and student learning self-assessment

Case study methodology allows for reducing the time devoted to lectures by forcing the student to self-learning it out of class. However, due to the lecture time reduction, the number of questions posed by the students about the theoretical knowledge to be learned is expected to decrease, as well as the number of different methodological strategies used by teachers in lectures, as particular examples, different approaches for explaining the same concept, questioning students in class, etc. As the deep acquisition of the knowledge must be assessed in any case, additional resources must be created to assist the self-learning and the assessment of the degree of learning. These resources can consist on tests about theoretical concepts, simple numerical exercises, multimedia content, simulators, virtual labs, etc.

Cases may be designed so that they can be used in different subjects

In order to maximize the acquisition of problem solving skills, a special effort should be done for the case to have sufficient complexity and cover multiple knowledge areas. Succeeding in this goal opens a wide field of applications of each case developed. Table 1 shows an example for the use of different cases in different subjects.

Table 1. Example of use of different cases for different subjects

	Subjects				
Cases	**Vibrations in machinery**	**Tribology**	**Machine elements design**	**Engineering design**	**Machinery maintenance**
Case 1: failure of a combine harvester speed reducer		Oil selection Wear rate estimation	Bearing design Gear design		Maintenance strategy
Case 2: failure of a ski station cableway	Dynamic amplification factor Dynamic systems modelling			Redesign process	
Case 3: excessive vibrations in a steam turbine	Rotordynamics modelling Campbell diagram Flexible rotor balancing	Hydrodynamic bearing behavior in non-nominal conditions	Bearings, seals and couplings		Predictive maintenance models
Case 4: acceleration system for a suburban train	Dynamic systems modelling		Spring design	Concept design	
Case 5: package design for a desktop printer	Free vibration Shock analysis			Concept design	

Cases must fulfill some requisites in order to allow for an effective learning process

As (Shapiro 2014), (Herreid 1997), (Danziger) have magnificently explained, some rules must be followed in order to achieve student excitement and attention. Storytelling is an effective tool for that, as can be seen from very young aged children. Furthermore, stories evoke feelings, so student empathy can be triggered in order to assume the real situation. A main character is then needed in the story, as well as quotes of his/her thoughts. In addition, the case must inspire students and motivate them to carry out the required problem solving process. For that, an interesting issue, involving a real situation, with a considerable challenge (for instance, high repair cost or lost profit, many possible alternatives, high technology involved…) must be used, better if it develops in a well-known environment -for instance, a multinational company-. This evidences the importance of the industrial and/or technological services experience in the teacher curriculum. A good case must also induce contradictions and force trade-offs, so that the problem solving process can be correctly performed by the students. Finally, case must force a decision making activity, which is an essential part of the problem solving process. The decision must be based in a wide alternative synthesis work, followed by a careful alternative evaluation based on relevant criteria.

Teacher personality and character are crucial for the class session (Bayona 2017), as a lead role is needed in order to correctly manage time, conduct discussions, highlight correct points of view, encourage participation, etc. Practice is the most important tool for achieving this. However, teaching guides can be written in order to assist less experienced teachers in the preparation of the class sessions.

PROPOSED METHODOLOGY

As Figure 1 depicts, the proposed Case Study-CDIO combined approach establishes two separate activities: out of class and class work. During the out of class work stage, students are expected to carry out individual study of the theoretical content -whose learning can be evaluated by means of self-assessment activities- and a subsequent teamwork in order to prepare the case discussion to be performed later in class. Certain freedom is given to the students to organize the groups. Resources for the individual work have been developed (see next section), as graphical handbooks, Matlab simulators, excel tables, videos and problem collections. For the evaluation, several Kahoot! tests have also been created. The case is also available to the students since the beginning of the course, so they can prepare it anytime.
During the class, each team will explain their solution and hold their arguments and reasoning behind their thought process, with the teacher serving the role of a moderator. In order to check the acquisition of the theoretical content, additional Kahoot! tests have been developed so that they can be done at the beginning of the class. After the case discussion, a design alternative will be decided. A prototype of this alternative will be manufactured and tested with the available lab facilities and testing devices (see next section).

SOME APPLICATION EXAMPLES

Spring design

A case has been written for encouraging the students design a spiral spring for increasing the acceleration of a three-car train. The train has initially just one electrical motor, located at the first car, so adherent mass is not enough to reach the target acceleration. The installation of additional electrical motors in the remaining cars is not possible due to size restrictions, even though this solution could be implemented with a redesign of the car, with a reduction of the number of passengers transported. Consequently, the cost of the springs must not be greater than that corresponding to the electrical motors solution. As a trade-off between energy stored in the springs and spring weight (that is, cost) and service life (that is, maintenance cost), spring materials, spring shape and stress level must be optimized. Mechanical connections, transmission and required electronic regulation are also to be designed, so this multidisciplinary problem can be taught in subjects as “machinery elements design”, “machinery maintenance”, “dynamic systems simulation” or “Systems control”. Figure 2 shows an excerpt of the case, where annexes corresponding to the results of fatigue testing of carbon fiber composites and a table showing the transient calculation of the acceleration with certain spring are shown. In order to check the spring design validity, a PLA scaled prototype must be designed and tested in a simple device created for that purpose, as Figure 3 shows. Students can manufacture the spring prototype with any 3D printers available at the lab. For the spring design, the PLA stiffness and allowable stress must be available. Simple specimen testing can be carried out in order to calculate these parameters. In order to prepare the case, different support resources have been developed for the students, as a Kahoot! 20-questions test and a tool for the calculation of the transient acceleration as well as the system parameters, which allow students to test different spring designs.

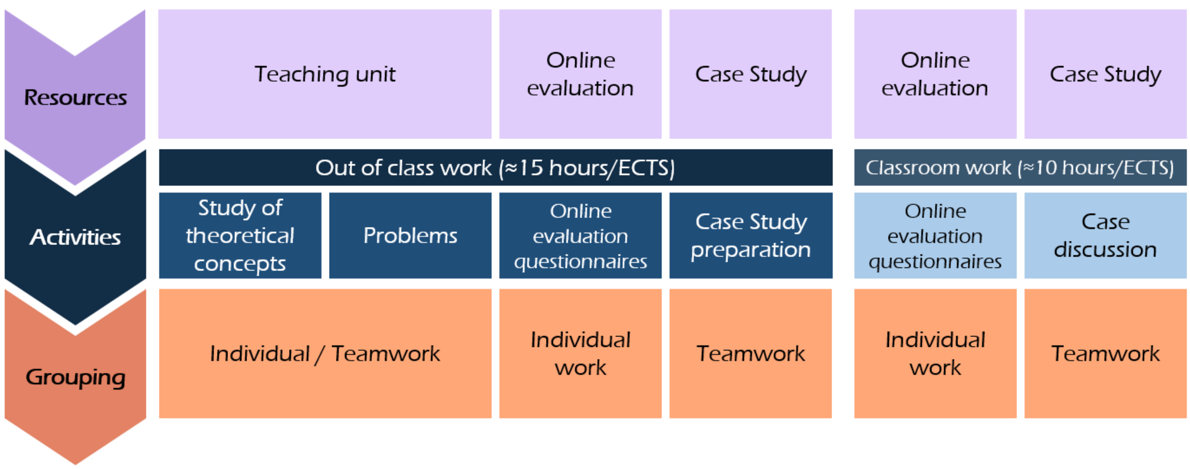

Figure 1. Proposed methodology, including resources, student activities and grouping.

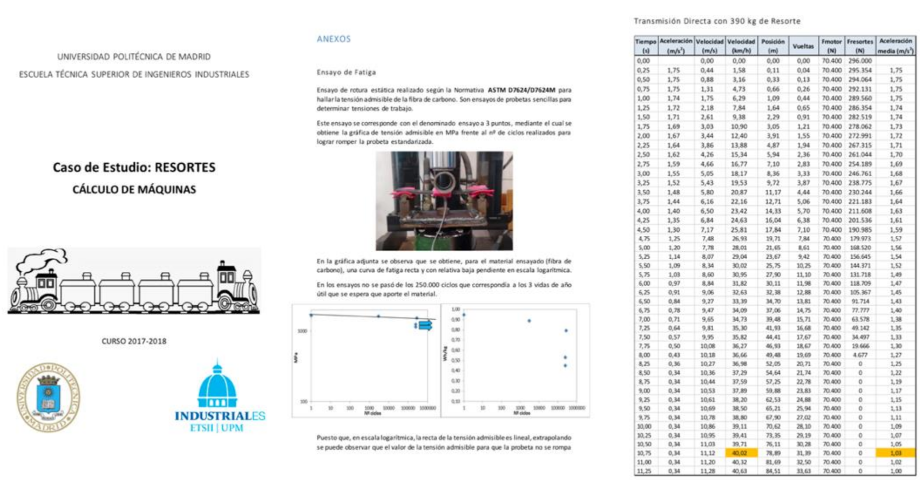

Figure 2. Excerpts from the case “Spring design for acceleration increase”.

Figure 3. Prototype spring testing device.

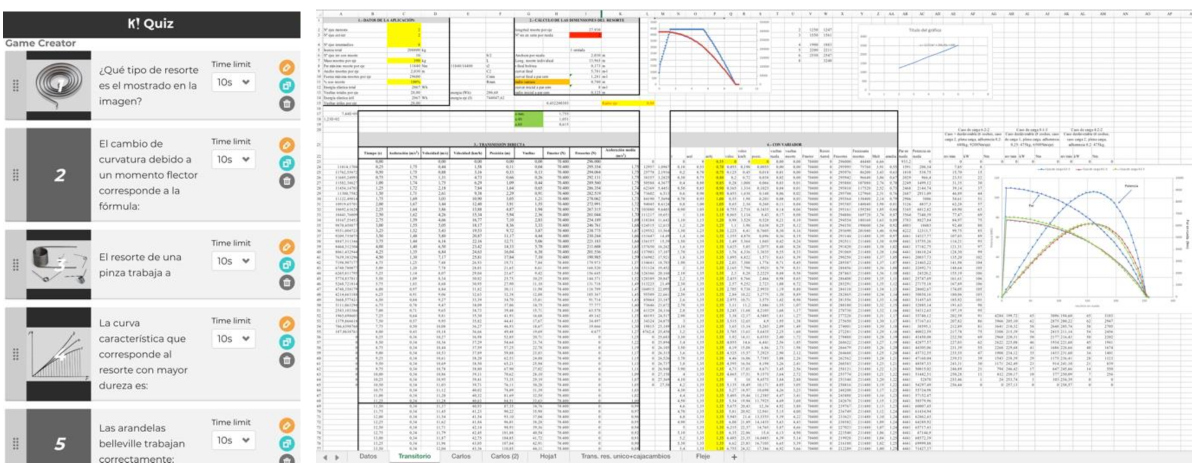

Figure 4. Self-evaluation test about spring design in Kahoot! application and helping tool for the calculation of the system transient parameters.

Vibration analysis/Design focused on vibrations

A case related to machinery failure detection by means of its vibration signature is used in the “Vibrations in Machinery” subject. It is related to a real life problem, in which a steam turbine catastrophic failure causes were analyzed by some of the Machinery Engineering Division teachers. The failure was related to rotor-stator rub due to a combination of unbalance and misalignment. A simple rotating machinery vibration simulator is used (Figure 5) to reproduce a rub and measure the vibration signal by means of a proximitor. Rotor balancing is subsequently carried out. A modal balancing spreadsheet has also been developed.

Figure 5. Rotating machinery vibration simulator.

Machinery failure analysis

A case related to the failure of a worm gear used in an elevator machinery was also prepared (Figure 6a). Some teachers of the UPM Machinery Engineering Division were involved in the failure analysis. The failure was related to an incorrect selection of the lubricant. Students must analyze the working parameters, from which the contact forces and relative speeds can be obtained. A thermoelastohydrodynamic model is then used in order to determine the operation temperatures and oil film thickness, which allows for the determination of the wear rate. The same operation can be carried out by testing different lubricants in order to select an appropriate one. The case is designed in such a way that students are conducted to the selection of a lubricant which cannot be finally used because of non-technical reasons (use of other lubricant in a different machine family).

Finally, students can check the real machine operation in a machine prepared in our lab for this purpose (Figure 6b). Surface roughness in elements operated with the correct and incorrect lubricants can also be checked by means of a surface roughness tester or a confocal microscope also available at the lab.

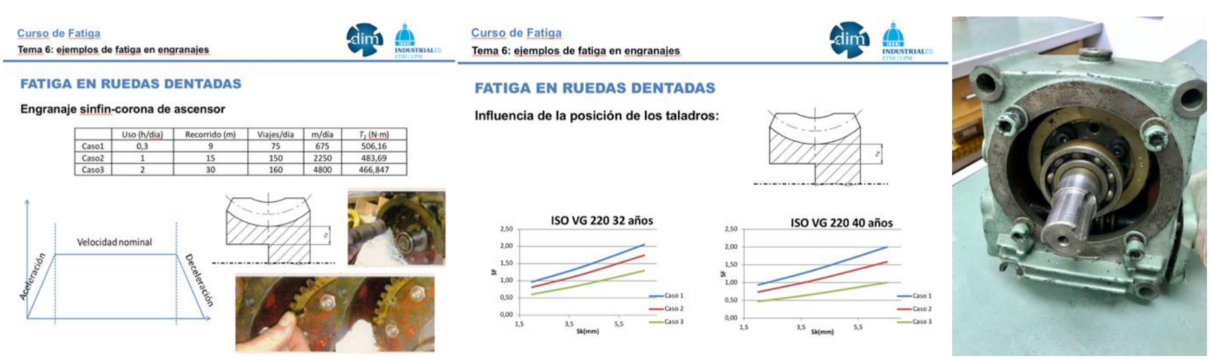

Figure 6. a) Case study, machinery wear failure. b) real machine in the laboratory.

Packaging design

A case has been written to encourage students design the packaging of a desktop printer, in the framework of the teaching of “1 degree of freedom systems” in the “Theory of Machines and Mechanisms” subject. Students must select the packaging material, thickness and surface in order to protect the printer from a free fall from 1,8 meters, corresponding to a nominal potential failure during the warehouse handling. Students are given a list of allowable materials (as bubble paper, PS foam, corrugated cardboard, folded paper, etc.). Students must perform simple tests to obtain the material stiffness and damping ratio as a function of its thickness. A mobile phone accelerometer is used for this purpose. A trade-off between stiffness (reducing maximum acceleration but increasing packaging deformation) and damping (reducing packaging deformation but increasing maximum acceleration) must be found. In addition to the case, Kahoot! tests, simple problems for autonomous study and a Simulink tool (Figure 7) for the simulation of the transient behavior have been created. In graduate subjects with a high number of students enrolled, the case study methodology may not be applied, substituting the class play with an individual or group work aimed to the design. Teacher can perform the stiffness and damping estimation in class, or encourage students to do it by themselves.

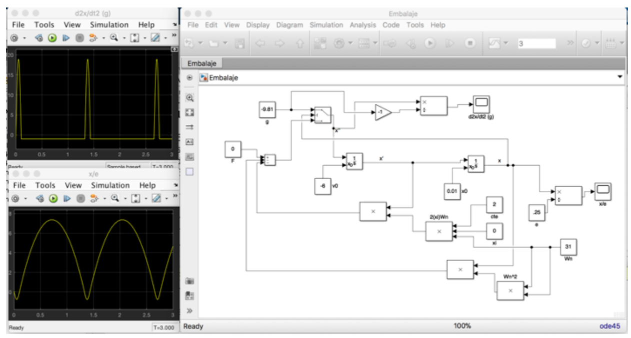

Figure 7. Simulink tool for the testing of different packaging design solutions.

CONCLUSIONS

The implementation of a combined CDIO-case study methodology allows for improvements in the quality and effectivity of the teaching-learning process:

- The acquisition of knowledge and skills related to the application of theoretical knowledge to complex integration problems in mechanical engineering, as the number of open problems solved by the students is increased.
- As a result, the acquisition level of the theoretical knowledge is increased, as students are required to a higher level of self-learning and teacher advising.
- Teachers have a better control of the student out-of-class activities, provided that information about self-assessment tests is available.
- Student motivation is improved through the inherent competition environment and the manufacturing of test setups arisen from their design work.
- Teacher motivation and skills are also improved, provided the need of managing the class discussions arisen.

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BIOGRAPHICAL INFORMATION

Dr. Juan Manuel Muñoz Guijosa is a Professor in the Department of Mechanical Engineering at ETSII – UPM. His research activities are linked to several fields of Mechanical Engineering, including vibrations theory, composite and nanocomposite materials and product development systematics. He has been linked to subjects on "Mechanism and Machine Theory", "Vibrations Theory", "Engineering Design", among others, and leads several public and private funded research projects, resulting in different patents and research articles and incorporating research results to the teached subjects, being very active in the field of project-based learning.

Dr. Enrique Chacón Tanarro is a Professor in the Department of Mechanical Engineering at ETSII – UPM. His research activities are linked to several fields of Mechanical Engineering, including most areas of tribology and contact phenomena, machine performance assessment and systematic product development applied to energy engineering. He incorporates research results to subjects on “Machine Design”, “Tribology”, and “Engineering Design”, and participates in several public- and private-funded research projects.

Dr. Andrés Díaz Lantada is Professor in the Department of Mechanical Engineering at ETSII UPM. His research activities are aimed at the development of biodevices, based on special geometries and on the use of smart materials, with the support of computer-aided engineering resources and solid freeform manufacturing technologies. He incorporates research results to subjects on “Bioengineering Design”, “Design and Manufacturing with Polymers” and “Computer-aided Mechanical Engineering”. He has been guest editor for the International Journal of Engineering Education for the special issues on “Learning through play in Engineering Education”, “Collaboration Academia-Industry on Engineering Education”, “Engineering Education: Beyond technical skills” and “Engineering Education for all”.

Dr. Javier Echávarri Otero is Professor in the Department of Mechanical Engineering at ETSII – TU Madrid. His research activities are linked to several fields of Mechanical Engineering, including most areas of tribology and contact phenomena, machine performance assessment and systematic product development. He incorporates research results to subjects on “Machine Design”, “Tribology”, and “Engineering Design”, and participates in several public- and private-funded research projects. He leads a project funded by the Spanish Ministry of Science and Innovation.

Mr Álvaro Guzmán is a Student currently undergoing his Master Studies in Industrial Engineering at ETSII-UPM. He is currently carrying out his research work in the field of mechanical vibrations and tribology. He has been involved in the CDIO “Product Development” Course as fellow for the creation and development of learning resources for the application of the case study methodology.

Corresponding author

Dr. Juan M. Muñoz-Guijosa
ETSI Industriales – Tech. Univ. Madrid (UPM)
C/ José Gutiérrez Abascal, 2
28006. Madrid. Spain
+34913364216
jmguijosa@etsii.upm.es

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MATH FOR ENGINEERING STUDENTS

Hans Peter Christensen

Technical University of Denmark

ABSTRACT

At the Technical University of Denmark all the Bachelor of Engineering programmes have the same courses in Mathematics given by the Department of Mathematics. In this paper, two exceptions to this are discussed: A successful course and one cancelled after a pilot run. At the Arctic Engineering programme math is combined with physics in a course, where the students learn math in a CDIO way by translating a physical model for an engineering case into a solvable mathematical model. Most students think they get a good understanding of math and the way the math works behind the physics. In 2014 a math course modelled on the Arctic Engineering course, but with the Math Department giving the math classes, was developed for the Civil Engineering programme. However, the math teacher did not use the cases for motivation but required the students to do traditional math exercises. The students were unhappy with the course, even though the failure rate was lower and the average grade higher than for the standard Math course. The good experience from the Arctic Engineering programme shows that it is possible to use engineering cases as motivation for math without losing focus on the math theory. But math teachers must be convinced that engineering students have better ways to learn math than with the traditional theoretical approach.

KEYWORDS

Mathematics, interdisciplinary courses, course design, Standards: 2, 7, 8

INTRODUCTION

How do you teach mathematics to engineering students?

At the Technical University of Denmark (DTU) the Department of Mathematics gives the math courses. All the Bachelor of Engineering (BEng) programmes have the same math courses with a few exceptions.

This paper first analyses the challenges in teaching math to engineering students and then discusses two alternative math courses – one successful for 10 years and one cancelled after a pilot run.

THE CHALLENGE TO TEACH ENGINEERING MATH

Teaching math to engineering students is a challenge – both to the teacher and to the students. The teacher faces students that do not seem to be overly interested in math, and the students often face teachers that do not know the students' use of math in other courses and future jobs. Math classes to engineering students often become more a question of survival than of engaged learning.

The question is how to teach math, so it is useful in engineering and thereby motivating for the student, and at the same time gives the student a general understanding of math without reducing math to a tool to solve an engineering problem.

What is the role of math in modern engineering?

In the beginning engineering was not based on science but only on practice. The old Romans build their aqueducts, some of which are still standing, without the mathematical basis used for modern bridge design. With the scientific rebirth in Western Europe after the Enlightenment engineering got its science foundation, and during the last century engineering education became increasingly theoretic. As a reaction to this, several initiatives have been initiated to bring back practice to engineering education (ALE, CDIO). This trend, however, has not to any extent fundamentally changed the way engineering students are taught math.

Actually, there is a lot of focus on teaching math to engineering students – there are written many papers on teaching engineering math (e.g. Croft & Ward 2001). This shows the need for developing math teaching – unfortunately it also shows how the target is missed. Most papers on math for engineers are written by mathematicians, who discuss how to optimize teaching in a math for math way. New IT tools have been introduced, and math classes have been supplemented by projects and active learning (Ferreira, Nicola & Figueiredo 2011), but this is not enough to motivate students, if they do not see a purpose for learning the math.

Math is an abstract science with an epistemology based on coherence – you seek a set of axioms that are not inconsistent. The epistemology of engineering is to seek something that works, so you can meet specified goals – it does not really matter, if the model used is self-consistent as long as you get useful results. Most engineering disciplines have a mathematical basis, but for practical engineering math is rarely very visible. In modern engineering math has become a behind the scene activity carried out by machines. Only for very specialized engineering math is a primary tool (see e.g. Journal of Engineering Mathematics), but most engineering students do not end up in these jobs – certainly not BEng graduates.

What the engineering student needs is to be able to transform the physical world into a strong mathematical model, put this into a computer, and assess the validity of the output.

Now back to the original question: How to teach math to engineering students?

There are basically three approaches to teaching math in an engineering programme: Stand-alone math courses, integrated math in engineering courses, or integrated engineering applications in math courses.

The standard way to teach math to engineering students is to leave it to the Math Department. The Math Department is staffed with mathematicians, who think math is beautiful in its own right and get very disappointed, when their engineering students do not share this fascination. And they often have large classes with students from different programmes, making it difficult to motivate and engage the student.

An alternative to this is to let an engineering teacher give pure math classes. However, over time the task of giving the math is often delegated to specific engineering teachers, who end up as math teachers.

The two other methods may seem like much of the same, but there is a significant difference. In one you get rid of the mathematicians from the Math Department and integrate the math into an engineering context, which in principle is the optimal solution giving high motivation (Brandsford et al. 2000 p. 60). In reality, it is not so simple. First, many engineering programmes do not have suitable engineering courses requiring the right level of math. Second, it is difficult for an engineering teacher to focus sufficiently on the theoretical side of math, when the real interest is in the engineering application. Third, learning math based on applications in only one field results in the math being context bound (Brandsford et al. 2000 p. 62); you need examples from different applications in order to generalize.

In the last approach, the math teachers still teach the math, but teachers from the engineering departments participate. Math is the primary learning objective – the engineering part is primarily for motivation; learning the engineering topic is an added benefit. A variation of this is that a qualified engineering teacher also teaches the math. Both variations will be discussed here. First the approach with an engineering teacher giving the entire course, and then the approach with a mathematician giving the math.

MATH AT THE BEng PROGRAMMES AT DTU

The BEng programmes focus on the practical aspect of engineering in order to make the graduates ready for a job, in contrast to the more theoretical Bachelor of Science in Engineering programmes, which are the first step to a Master degree.

Each BEng programme had their own math courses taught by an engineering teacher until 1995, when a restructuring resulting in all BEng programmes should have the same two 5 ECTS math courses given by the Math Department. An exception to this was the programme in Arctic Engineering as described in the next section.

Following a new reorganisation the plan was that the two math courses should be replaced by small math modules, from which the different programmes should select 10 ECTS relevant math topics. In reality, all programmes ended up including a common 5 ECTS math course in their first semester: BasicMath. An exception to this was an experiment at the programme in Civil Engineering as described later.

The students have many difficulties with the BasicMath course. Many students fail the course and the average grade is low. The results for the first six times the course was given are shown in the first part of Table 1.

Most students start in the fall right after high school. The students starting in the spring are older students with varying backgrounds, and they have generally more difficulties with math than the younger students directly from high school.

Table 1: Passing rates and average grades on a scale from 0 to 12 with 02 to pass.

		Passing rate	Average grade
BasicMath	Spring 2017	66	3.7
	Fall 2016	72	4.8
	Spring 2016	62	3.7
	Fall 2015	80	5.6
	Spring 2015	80	5.3
	Fall 2014	81	5.9
	Average all	**74**	**4.8**
	Average Spring	**69**	**4.2**
Math in Physics	2017	63	4.6
	2016	77	5.0
	2015	70	5.2
	2014	55	2.5
	2013	73	5.1
	2012	80	5.0
	Average	**69**	**4.6**
Math for CivEng	**Spring 2017**	**79**	**5.8**

THE BEng PROGRAMME IN ARCTIC ENGINEERING

The BEng programme in Arctic Engineering is special, since a majority of the students are Greenlandic, and the first three semesters take place in Greenland. Due to this the programme for logistics reasons has a compressed math course, with classes given every day. In 2007 the curriculum for the first three semesters was according to the CDIO principles reorganized into large interdisciplinary courses (Christensen 2008, Ingeman-Nielsen & Christensen 2011), and a new combined math and physics course was introduced: Math in Physics.

The Math in Physics course

Before the reorganization the Math Department gave the math, and the math teacher had actually designed some very good examples from engineering: ballistics, vibrations of a moving car due to bumps in the road, and oscillation of a high rise building due to an earthquake. But the examples were used in the classical math class approach: First the necessary math was given, and the physical model was elaborated and transferred into a mathematical model by the teacher – then it was up to the student to solve the resulting differential equations.

In the new course given by an engineering teacher, this is turned somewhat upside down. The students are given a realistic (although often somewhat tinkered) case – it could very well be about ballistics (all in Greenland goes hunting) or about the suspension of a car (and even better a snowmobile) – and have to create the physical model and translate this into a mathematical model themselves, before they can solve the equations.

Teaching in the course is planned with an inductive need-based approach (Kurki-Suonio & Hakola 2007). A typical teaching sequence starts in the middle of a lesson, when new concepts are introduced, and a new assignment is given. The students then study the theory and learn the new math by applying it in problem solving. In the start of the next lesson the theory from the previous lesson is summed up, and the solution to the assignment is discussed. The sequence is finished, after a new is started, when handed in assignments are quickly returned with the teacher's comments.

Right from the start complex assignments based on realistic cases are used, since standard textbook drills with given results do not crater understanding and creativity (Cropley 2001 p. 160). The challenge is that real-world problems very quickly get much more complicated than you want for the first course in math. So the complex assignments have to be very structured and solved in a spiral way. The same case may be used for several sequences – becoming more and more realistic and requiring more and more mathematical concepts to handle.

The exam must satisfy two requirements. From an engineering point of view you want to test the students' ability to solve problems – in math you want to test their conceptual understanding. The ability to solve problems is assessed with a 1½ day assignment. To assess the students' conceptual understanding a 1 hour closed-book multiple-choice like test is given.

Evaluation and discussion

The exam results for the last six years are given in the middle section of Table 1. The results are comparable to those for the BasicMath course, but in reality, they are better than could be expected, since the Greenlandic students for cultural reasons come with a weaker background and score in average approximately 2 grade points lower than their Danish colleagues.

All courses at DTU are evaluated by a standard student evaluation. The following quotes are from the evaluation in 2011, where additional evaluation was done.

Good: *The assignments were fun, even though they were difficult. It was good that [the assignments] were structured step by step. The feedback on each assignment helped me understand the course topics.*

Not so good – suggested changes: *More assignments, but smaller and easier. Fewer assignments so we can work more in depth and get a better understanding.*

The teacher had to agree with these complaints. It is easy to get carried away, when you want a case to get as realistic as possible. Since then there has been more focus on also giving the weak students some good experiences. And fewer assignments are to be handed in.

In 2011 the students were also asked to do a self-evaluation of their learning in the course. A few states that they have learned math like differentiation and integration, but many writes about the understanding they have obtained of physics and the relation between math and physics: *I have obtained a better understanding of differential equations concerning* *acceleration, velocity, and position. To transform physics to math language. A lot about the formulas behind the formulas we have used e.g. in statics.*

The students should indicate the most important they have learned and the most difficult in the course.

Most important learning: *To understand the laws of physics via math. To set up Newton's 2nd law in Maple and transfer this to a differential equation.*

Most difficult: *To think in math-physics terms. To understand and get into this way of thinking.* The practice-based approach used in this course should help bridge the gap between engineering and abstract thinking, but it probably also highlights the difference in the beginning.

Most students find the learning is good in this course. However, not all students are completely happy with the course. The two most frequent complaints are "too much work" and "the realistic cases are too complex and not easy to solve". Most students have the idea that a good assignment is one, they can solve, not realizing that they learn little by solving problems they already know how to solve. A little frustration is good for learning, as long as it does not kill the motivation. Most students appreciated the structured approach with increased difficulty, and they liked to work with the same case for several days, giving them time to get a good understanding of the problem.

An encouraging aspect of the student evaluation was the positive comments about feedback – one of the most common complains in student evaluations is insufficient feedback. The comments about learning the math behind the physics and the better understanding of dynamics are also encouraging – and should be seen in relation to the severe difficulties many students have with the conceptual understanding of fundamental physics. And even though the students may feel that they mostly learn physics, in reality, what they learn is mostly math, and how to use math to model the real world.

THE BEng PROGRAMME IN CIVIL ENGINEERING

After some changes to the BEng programme in Civil Engineering the standard BasicMath course was as an experiment in spring 2017 replaced by a specially developed course on Math and Physics: Math for CivEng.

The Math for CivEng course

The math teachers did not want to participate in this, but the dean required that the Math Department should be responsible for developing and giving this course. It was designed by two math teachers and an engineering teacher, and the compromise was a course structured like the Arctic Engineering course, but with only four teaching cycles called Mini Physics Projects, even though the content was mostly math. Each cycle consisting of a) modelling a physics problem into a math model with the engineering teacher, b) presentation of the math needed to solve the problem with a math teacher, c) the students solving the problem with the help of teaching assistants, and d) discussing the physical meaning of the mathematical solution with the engineering teacher.

This seemed reasonable. The cases were derived from those used in Arctic Engineering and designed and formulated so the students had to use the math given in the math classes. However, in the implementation the math teacher used purely standard x-y examples without reference to the case and gave the students traditional math homework in addition to the work on the Mini Projects. And the math teacher insisted that the final part of the projects were not given to the students before they had done the pure math assignments. This meant that the students had very little time to work on the projects.

This structure made the students very frustrated. They loved the high-school way the math was given but hated the more complex physics problems, which they felt were too difficult with the limited time and teacher assistance available.

The exam consisted in assessments of the Mini Physics Projects and the math homework, and a written math exam – except for the Mini Physics Project this was the same model as for the BasicMath course.

Evaluation and Discussion

69 students participated in the Math for CivEng course. The students had a slightly better grade average than for the standard BasicMath course as shown in the last line of Table 1.

The planned throughout evaluation of this experimental course was not carried out, since it was clear that the structure and implementation had to be changed.

The answers to the three most relevant statements in the student course evaluation are compared to the answers for the BasicMath course in Figure 1.
The statement Q1.1 is: I think I learn a lot in this course
The statement Q1.5 is: I think the teacher/teachers create a good connection between the different teaching activities
The statement Q1.8 is: All in all I think it is a good course

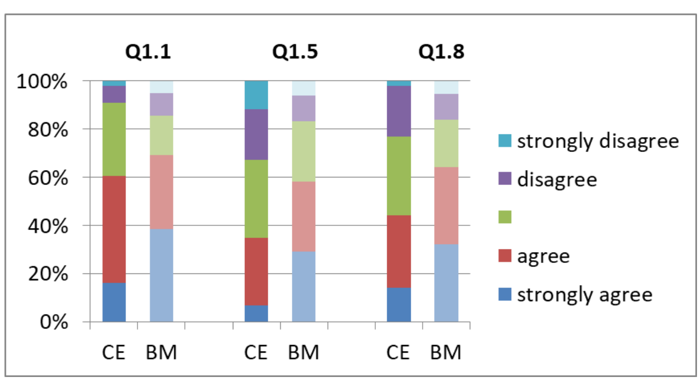

Figure 1: Answers to statements Q1.1, Q1.5 and Q1.8 in the student course evaluation.
CE stands for the Math for CivEng course.
BM stands for the BasicMath course average from fall 2014 to spring 2017.

The evaluation for the Math for CivEng course is bad, as it should be, but not as bad as it could be expected to be due to all the problems with the course. It is interesting to observe that relatively fewer students than for the BasicMath course think they have not learned anything and strongly dislike the course. A few students even think that there was a good connection between the math and physics part of the Math for CivEng course.

The following is a few of the students' comments.

The physics part has been a bit confusing, particularly because there was so long time between each lesson…

After the physics part (phase 1) you get 4-6 questions, which generally is not that difficult to do. But as soon as the math part is over, 10 physics questions (phase 2) are added to the assignment, which makes the assignment very unclear, considering you only have 2 days to finish the assignment.

There were very few positive comments:

I think the [connection] between physics and math is good, since you realize, where you use the math you learn in reality.

The physics teacher got bad evaluation:

I have difficulties to understand the course, since the teacher shows very little interest in teaching us.

Whereas the math teacher got very positive evaluation:

The teacher makes good use of the blackboard, which makes it easier to follow the lecture and take notes. At the same time, the tempo is adequate, and you feel you that you achieve a lot each time.

The students were told at the start of the course that they would meet very different teaching styles – traditional high school teaching in math and university style teaching in physics. But with the skewed planning and very little teaching assistant time allocated to the casework, the students could not appreciate the independent way of studying.

The basic problem was of course that the Math Department did not want to participate in this experiment, so they did not accept the principles for the course and align the math part accordingly. But then the engineering teacher was not prepared for the fear that the math teachers had for not giving the math in the traditional way. The engineering teacher was under pressure to make this course ready for implementation and in hindsight accepted too many compromises. However, it might have worked, if the original intentions had been implemented.

An acting dean decided that the experimental course should not continue after the pilot run, and the programme should return to use the BasicMath course until it would be possible to design and implement a better course.

CONCLUSION

As the experience with the Math in Physics course at the Arctic Engineering programme shows, it is possible to do a useful integration between math and applications, so the engineering aspect of mathematical modelling is enhanced and at the same time focus is kept on the math theory. However, it is not easy to implement. The assumed optimal way, where math teachers work with engineering teachers, was a failure due to a reluctant participation from a Math Department.

To succeed math teachers must be convinced that engineering students have better ways to learn math than the classical deductive way. And something has to be done, since far too many students, as the statistics for the BasicMath course show, have difficulties in getting a good experience with math.

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BIOGRAPHICAL INFORMATION

Hans Peter Christensen, PhD is an Associate Professor and Director of Study for the BEng programme in Civil Engineering at the Technical University of Denmark (DTU). He has worked with teaching and learning, helped start the teacher training programme at DTU and been head of the Active Learning in Engineering Education (ALE) network.

Corresponding author

Dr. Hans Peter Christensen
Technical University of Denmark
Lautrup Parken
2750 Ballerup
Denmark
+45 2032 1303
hpch@dtu.dk

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ELECTIVE PROJECT COURSE: REALIZING THE ACADEMIC INTERESTS OF STUDENTS

Flor Angela Bravo, Jairo Alberto Hurtado, Carlos Ivan Paez

Electronics Department, Pontificia Universidad Javeriana. Bogota - Colombia

Ana Victoria Prados

Electronics Department, Pontificia Universidad Javeriana. Cali - Colombia

ABSTRACT

Even before entering to university and during their engineering studies, many students have personal interests related to different areas, which are not necessarily covered by the theoretical or practical courses. These topics of interest to students are a great opportunity to start working as projects, even from the first years of the program and with the help and support of some professors, they would contribute to strengthen their skills as engineers. Electronics Engineering program at the Pontificia Universidad Javeriana, Colombia, decided to open an elective course called Special Projects on Electronics Engineering, in which the students, with the guidance of the professor, define the projects to be carried out under the CDIO approach. Through the process of conceiving-designing-implementing products, processes, and systems; students develop a project of their own interest related to electronic engineering. The idea of this course was originated as an alternative of academic recognition of the work done by the students linked to the research groups. Currently, the class has been structured in such a way that at the end of the course students must submit the functional prototype of their project, attaching to document, tutorial, video or poster to socialize and give visibility of the work done. The document is structured as follows: first, it details the structure of the course and the learning outcomes. Then, the methodology and the competencies that will be developed are shown. After that, the projects of some students are presented. Finally, lessons learned, and conclusions are given.

KEYWORDS

Engineering education, project-based learning, educational innovations, collaborative learning, active learning, Standards: 7, 8.

INTRODUCTION

Student Research Groups have as one of their objectives to link undergraduate students in the development of research activities, in order to develop research skills and abilities. Despite the enormous work they do in their free time, in order to carry out projects and keep these groups functioning, the students do not obtain any recognition in academic credits.

From this situation, we looked for ways to offer academic recognition to these students for their work and we had the idea of creating an elective course. Initially, this class was designed for the students belonging to these research groups so that they could carry out their work and also have recognition of academic credits.

After submitting the proposal of the new class to the School Council, including syllabus and methodology, the new course on Special Projects in Electronic Engineering was approved, which was offered for the first time in January 2017. This course provides engineering students with spaces and support to develop projects of their interest that are related to electronic engineering.

Although this class was born with the idea of offering credit recognition for students linked to research groups, after the first version, several engineering students who want to develop projects on a specific topic that is not necessarily covered by the courses of their academic program or in the research groups, asked to take this class.

Elective courses could be an alternative to provide students with a space to develop projects of their interest, especially projects related to their career, and with support of classmates of higher semesters, professors or even graduate students.

Special Projects on Electronics Engineering gives students the opportunity to put their knowledge into practice and foster the development of skills (personal and interpersonal), such as collaboration, team work, creativity, problem-solving, critical thinking, communication, and responsibility.

Electronics Engineering program at the Pontificia Universidad Javeriana program had been involved in a curricular review towards the implementation of the CDIO approach (Garcia, et al. 2014). The methodology of this elective course is based on CDIO approach. Through the process of conceiving-designing-implementing products, processes, and systems (Crawley, et al. 2014); students develop their projects.

Special project in Engineering syllabus's is integrated learning experiences that lead to the acquisition of disciplinary knowledge and skills (CDIO Standard 7), using project-based learning -PBL- (Gunnarsson, et al. 2012) and active learning (CDIO Standard 8). This strategy involves students, as active participants, in their own learning process (Garcia, et al. 2014). Active learning help students make better connections among concepts and facilitate the application of this knowledge to complex, contextualized, and real problems (Crawley, et al. 2014).

This paper presents a description of this elective course and the applied methodology. This document wants to show how with the work of a few teachers concerned and interested by their students, students can be actively involved and motivated to learn more about their engineering program, developing projects that until now had not found a space, resources or an accompaniment to make them.

Compared to previous publications dealing with project-based learning the key points of this paper are that students can propose project tasks themselves and that the participants in the course can be from different years.

The document is structured as follows: first, a description of the course Special Projects on Electronics Engineering is provided. Then, the methodology and the competencies that will be developed are shown. After that, the projects of some students are presented. Finally, lessons learned and conclusions are given.

DESCRIPTION OF THE COURSE

Special Projects on Electronics Engineering is a theoretical-practical elective course of two academic credits (these two credits are equivalent to 3 ECTS). These credits correspond to one or two hours per week of work in the classroom with the accompaniment of a professor and four or five hours of independent work. Our academic period has 18 weeks, including two weeks of final exams and final projects.

Over each academic period the number of students has varied between 12 and 20 by each class, up to two different classes. time the course has been given. During the course the students are free to organize in groups from two to six students. It depends of the complexity of the project. Each project group has access to several technical experts.

Course Special Projects on Electronics Engineering was created as an alternative to the academic recognition of the work done by students linked to research groups, initially the Robotics Group (Bravo, et al. 2017), who demonstrated commitment and dedication of time in the development of their projects. Initially, the only requirement to enroll in this course was to be an active member of a research group. However, it is now available to all students of the engineering school. Mainly students of Electronics Engineering attended this elective course, also we have had a couple of students from Systems Engineering and Industrial Design.

In the course Special Projects on Electronics Engineering, students from different semesters can develop a project of particular interest that is not included in the core courses of the curriculum. The course provides students with conceptual and technical bases that help them in the planning, development, documentation, and execution of technical or research projects. Additional to the professor of the class, students can have the tutoring of professors and graduate students with expertise in the topic of the project.

At the end of this course, students should be able to:

- Integrate knowledge acquired in previous courses by developing a project related to engineering electronics that is of interest of them, under the guidance of a professor.
- Practice processes of conceiving-designing-implementing products, processes, and systems in the development of an engineering project.
- Apply engineering skills, such as, system thinking, measurement technics, comparison between theoretical and practical results, trouble shooting.
- Apply personal and professional skills and attributes, such as, problem-solving, creativity, collaboration, responsibility and communication (oral and written).

METHODOLOGY

The methodology of the course is based on the CDIO initiative and project-based learning (PBL). PBL is a learner-centered pedagogical strategy seeks that the students participate in the planning of a project, investigate and apply new knowledge and skills in the solution of a problematic (Bender, 2012), as an example of active learning (CDIO Standard 8).

Through the process of CDIO, students develop their projects, in such a way that in addition to acquiring knowledge and putting them into practice, improve their group work skills, develop their critical thinking and their communicative skills both written and oral (CDIO Standard 7).

Following, we describe the stages to develop the projects in this elective course (Hwang, 2017):

Preparation stage

This stage has two purposes; the first one, students introduce themselves to each other, it is necessary because, students are from different years or even programs. The second one is each student show and share project topics in a brainstorming of ideas to work, and have their first oral presentation, giving details of the work they wish to do in class. Sometimes students do not have a project in mind, so teacher give them some ideas of engagement projects to do.

Whole class evaluates each project. In this evaluation, aspects to be taken into account, suggestions, new ideas, possible difficulties and previous experiences in the subject are mentioned. Students of all ages, freshmen to senior can be in this class, thus the level of experience and knowledge is quite heterogeneous. Usually the best-structured projects are those belonging to the research groups, since the Conception stage has been carried out previously.

After that, students can find other colleagues who share the same interest for a topic or other proposals that call them more attention. It allows students create new alliances and reorganize their workgroups. It is desirable that students work in a workgroup. However, there are cases that there is only one student interested in a specific topic. In these cases, the student decides if he or she wants to work alone or if he o she wants to join another project that catches his/her attention.

Some professors with expertise in the topics of the project are invited to participate in this discussion. Finally, work groups are organized freely, to begin to define and limit the project to be carried out.

Conception stage

The purpose of this stage is the conceptualization of the project. Once the students have selected the problem they want to solve, they develop a report with the description of the problem, the methodology to arrive at the solution, the resources they need, the deliverables and the work schedule. Also, they must add a paper, taken from a formal publication, related to the topic in which they will work.

Among the deliverables are functional prototype and a document, tutorial, video or poster to socialize and give visibility to the work done. In this stage of formalization of the project, the professors advise the students in the structuring of a project that can be developed and delivered finalized in the academic semester. This stage allows students to be trained in specific aspects of the methodological process of a project.

Design stage

The purpose of this stage is to establish the project requirements and develop a design that meets these requirements. Under professor guidance, students are responsible for acquiring the knowledge and skills necessary to solve the problem or the selected need. Although the members of the work groups are students of different semesters, each student gives their contributions from their experience and knowledge.

Projects have involved some topics different to electronics, such as, mechanics, aeronautics, chemistry, etc, so students must to start to keep in touch with students and professors of other disciplines.

Each group must to share the design progress once a week. Professor can pick one of the students of the group to present the design status. They must present the design to the whole class to receive the feedback and the respective comments, as well as to answer the questions of their other classmates.

At the beginning, this stage is evaluated but not graded. Once all the questions or problems have been answered and corrected to the classmates or the teacher, the group will have its grade.

Implementation stage

In this stage, the students implement and test the proposed design. Students have 7/24 access to the workspace.

As part of evaluation, a different member of the group must present the progress and the status of the projects once a week. Problems presented during the implementation stage are discussed between the students of the class and the teacher. This is done so that everyone knows everyone's problems and learns from their colleagues or can give solutions.

If there is a topic that needs to be applied, but that is unknown to a large part of the students, the teacher explains part of this topic, so that all students can understand it.

Student must do all the tasks that lead to the project result.

Operation stage

This stage involves demonstrations of the prototype. It allows students to understand their prototype run in the real world. Additionally, they can obtain feedback from users and experts. As part of the final evaluation, they must present their project at a fair for electronic students, named Expoelectronica, at the end of the semester.

In this fair, they must show their project, sharing their achievements to the visitors, who are students of different programs, but they must also make a formal presentation before an external jury, who will evaluate them.

Presentation and evaluation stage

Before to go to the fair, students must expose to their colleagues and professor, the development, evolution and outcome of the project. Also, they must to present the technical documentation and final report (poster, article or video).

The professor of the course monitors the project progress in two ways. The first is through the weekly presentations of the progress that students have of their project in the classroom. These presentations allow students to know the projects of their classmates, who can contribute with ideas, comments and, suggestions. The second way is to review the binnacle that students report their work. Additionally, students can meet with the professor during student attention hours to show their current work status and request some advice. The student attention can be face-to-face or remotely through google hangouts. Students may also request the assistance of an expert in the topic of their project.

DEVELOPED PROJECTS

The projects developed in the course can be proposed by students, by a research group, or a professor. These projects can be technical or research and can be divided into the following categories:

- **Hardware**: In this category falls projects related to the design, construction of artifacts and mechanisms. Some developed projects are:
    - *Unmanned aerial vehicle (UAV) with solar panel for powering servomotors*.
    - *Multi-receiver radio frequency lights*.
    - *Plotter*. *(See Figure 1).*

Figure 1. 2D Plotter

-
    - *Sumo and minisumo robots. (See Figure 2).*

Figure 2. Students group (different years) in an International Sumo Robot Tournament

- *Robotic hand. (See Figure 3).*

Figure 3.Robotic hand

- *Access control systems.*
- *Quadcopter. (See Figure 4).*

Figure 4. Quadcopter

- *Identification system and decision making using Pixy camera. (See Figure 5).*

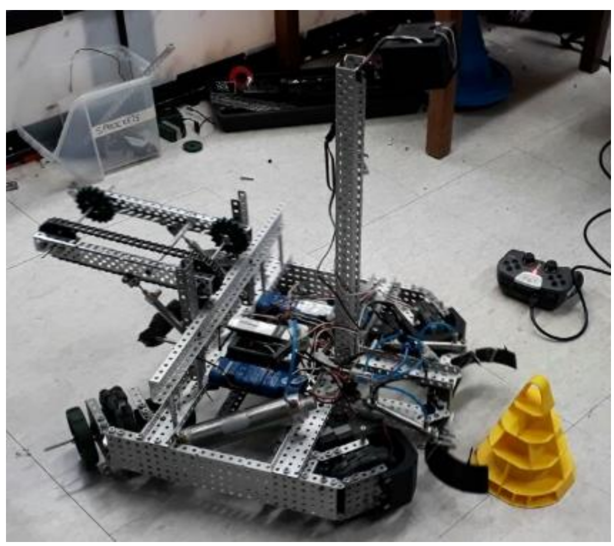

Figure 5. Robot with Pixy camera

- **Software applications**: It mainly includes the development of software applications. Some of the developed applications are:
  - *Bluetooth alert and search system*.
  - *Mobile application for robot control by Bluetooth*.

- **Education**: This category covers projects that develop guides and tutorials for educational purposes. It also includes projects related to the design educational activities using technological tools, such as robots. Example of developed projects include:
  - *Discovering renewable energies using Lego Education Renewable Energy kit*: *Storytelling with animatronic characters*. (*See Figure 6)*

Figure 6. Animatronic characters

- *Video for the construction of a test mobile base.*

- **Characterization and appropriation:** It includes projects related to the characterization and appropriation of components, tools, kits, or other equipment.
    - *Performance Study of Wheels and Motors of the Vex Robotics Platform. (See Figure 7).*

Figure 7. Robotics platform

- *Measurement and visualization of the charge level of the battery and other competing sensors.*
- *Prediction of useful life of lithium batteries.*

Some of these projects in Expoelectronics Fair and others events, are shown in the next figure.

LEARNED LESSONS

During the development of the class, different experiences have been had, which have served as a point of reference and learning, to improve the methodology used. Some of these learned lessons are the following:

- **Working with classmates of different semesters:** having work teams composed by students from different academic semesters was well accepted, especially by younger students, who were able to acquire concepts of their career in early stages (e.g., specifications of the electronic components) and relate to classmates from higher semesters.
- **Interdisciplinary student teams:** this course offers engineering electronics students the opportunity to work together with students from other programs such as industrial design and systems engineering.
- **Participation of professors and graduate students:** it also allows interested professors and graduated students to carry out projects with students.
- **Communication skills:** the elective course provide students with spaces to promote communication skills, such as writing, and speaking. In the reports generated by students, it was found that they lacked adequate writing skills, especially in freshmen students. Students received feedback on their writings and oral presentations. Additionally, they were given tips to make better presentations and reports.
- **Project management:** during the development of projects, students have to learn to manage time, manage a budget, and make national and international purchases of components and hardware.
- **Creativity and problem solving:** this course promotes the design of projects that solve problems or needs of the student or the community.
- **Student interest:** the development of the project of interest of the students increases their motivation to finish it successfully. In this process, students learn new concepts and develop skills.

CONCLUSIONS

Although the course was initially designed for students linked to research groups, students not linked to these groups have also been interested in carrying out projects. Offering the opportunity for students to develop projects of their own interest and not mandatory, helps them remember why they entered engineering and increases their motivation. Special Projects on Electronic Engineering class uses the motivation that students have for the development of projects of their interest, as the central motor of their learning. The oral and written expression of the students improves considerably when they must do it continuously, every week, as part of their project, which gives them an additional motivation. When asking or correcting their classmates does not affect the grade, but rather collaborates with the development of the project, the students do it more often and receive it better. Although it is a class designed for electronic engineering students, students from other programs such as systems engineering or industrial design have enrolled, which has produced very good results of joint work.

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BIOGRAPHICAL INFORMATION

Flor Angela Bravo, MSc. is a PhD candidate in Engineering at Pontificia Universidad Javeriana, Bogotá, Colombia. Her current research focuses on Educational Robotics and Human-Robot Interaction.

Jairo A. Hurtado, Ph. D. is an associate professor at Pontificia Universidad Javeriana Bogota, Colombia, at Electronics Department. He was Chair of Electronics Engineering Program and he has working in different projects to get a better process learning in his students.

Carlos Ivan Paez**,** Ph. D., is an Associate Professor at Pontificia Universidad Javeriana Bogota, Colombia, at Electronics Department. His areas of special interest are antennas, radio frequency, and Telecommunications.

Ana Victoria Prados, PhD. is an Associate Professor at Pontificia Universidad Javeriana, Cali. She was Chair of Electronics Engineering Program. Currently she is Director of Teaching and Learning Center.

Corresponding author

Dr. Jairo A. Hurtado
Calle 40 No. 5-50. Ed. José Gabriel Maldonado S.J.
Pontificia Universidad Javeriana
Bogotá, Colombia
57-1-3208320 Ext 5327
jhurtado@javeriana.edu.co

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"KIT PHYSICS NAVIGATION" SHOWING RELATIONSHIP BETWEEN HIGH SCHOOL AND UNIVERSITY

Tomoshige Kudo, Keita Nishioka, Akira Nakamura

Kanazawa Institute of Technology, Academic Foundations Programs

ABSTRACT

CDIO Syllabus and CDIO Standard suggest that engineering students should acquire fundamental scientific knowledge as the basis of CDIO in order to be able to apply it to disciplinary knowledge and should understand the connections between them. We have been developing an e-learning website of physics visualizing the connections between fundamental and advanced knowledge by using graph drawing. Also we have been developing a self-adaptive e-learning environment that learners can efficiently acquire integrated knowledge by connecting high school and university learning smoothly with hyperlinks on each webpage.

KEYWORDS

Scientific Knowledge, STEM, Self-Adaptive, E-Learning, Standards: 7, 8, 10,

INTRODUCTION

The CDIO (Conceive, Design, Implement, Operate) initiative advocates that the engineering students should try to foster the fundamental knowledge of mathematics, science, etc., as well as basic expertise. In Standards 7, it is suggested "with integrated learning experiences, faculty can be more effective in helping students apply disciplinary knowledge." And in Standards 8 it is suggested "instructors can help students make connections among key concepts and facilitate the application of this knowledge to new settings."

For example, if students have only the fragmental knowledge and cannot find the way to relate it with each other, it is difficult for them to solve the problems they found and to spark the idea. In order to be innovative, students should understand the relationship between the knowledge comprehensively and should learn how to relate them. Also they need to acquire knowledge of a wide range of areas, such as the mathematics, physics, engineering, etc. However, there is no self-adaptive e-learning website for STEM (Science, Technology, Engineering, Mathematics) which enables students to understand the relationship between the fragmentary knowledge. These days it's often the case that the students do an internet search by using a smartphone with the spread of it to find the answers for the problems they couldn't solve. Self-adaptive e-leaning website optimized for each student's knowledge will be of great help for them to acquire integrated knowledge and understand the relationship between the fragmentary knowledge by clicking hyperlinks on each webpage. Such a website should be designed to navigate students from a webpage which contains difficult concept to much easier concept with hyperlinks. Also, it should contain the knowledge structure of high school and university learning so as to provide students with comprehensive knowledge.

In CDIO Syllabus, it is indicated ‘‘the development of a deep working knowledge of technical fundamentals is, and should, be the primary objective of undergraduate engineering education.’’, and ‘‘Modern engineering professions often rely on a necessary core Knowledge of Underlying Sciences’’ (Crawley, 2001). Figure 1 shows Building blocks of knowledge, skills, and attitudes necessary to CDIO Systems (Crawley, 2001). Figure 2 shows Hierarchy of Technical Knowledge and Reasoning (Crawley, 2001). These figures show that Scientific Knowledge is the basis of all knowledge in CDIO Systems.

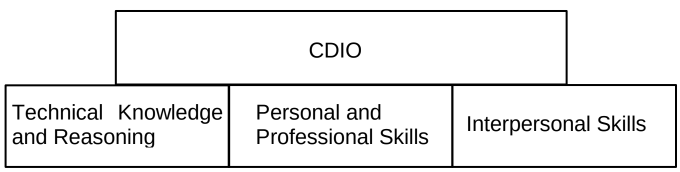


Figure 1: Building blocks of knowledge, skills, and attitudes necessary to CDIO Systems

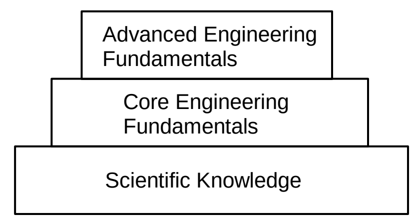


Figure 2: Hierarchy of Technical Knowledge and Reasoning

Various e-learning website have been developed (Negash et al., 2001). E-learning was a powerful instructional teaching and learning process (June & Leong, 2006), and a blended learning using e-learning was reported in connection with CDIO (Nyborg & Christiansen, 2016). Kanazawa Institute of Technology (KIT) published the self-adaptive e-learning website of mathematics, KIT Mathematics Navigation on the web in 2004. And the website stores over two thousand pages now. Recent KIT Mathematics Navigation has been developed in association with learning materials by combining print materials with web based training (Nakamura, 2011), graph drawing of knowledge structure of mathematics (Nakamura, 2014; Nakamura, 2015), and self-adaptive e-learning website of mathematics (Nakamura, 2016).

For the purpose of enriching the STEM e-learning environment based on the CDIO initiative, we published a self-adaptive e-learning website of physics, KIT Physics Navigation on the web in March 2016 (Nakamura et al., 2016) and developed a visualizing system of knowledge structure based on STEM e-Learning website (Nakamura et al., 2018). Multilingual translation is possible in Google translation. One of our concepts is to describe the connection between high school and university learning for the students to understand the relationship between the fragmentary knowledge smoothly. It is currently at issue that the university students have feelings of being not good at physics. As one of the reasons for this, it is mentioned that, there is a certain level gap of the knowledge among high school and university learning. For example, the differential and integral calculus is not used in the physics class of high school in Japan. It is needed to fill in the gap by connecting high school and university learning smoothly.

Here we report the details of self-adaptive e-learning website, KIT Physics Navigation. Firstly, we will explain characteristics of KIT Physics Navigation. Secondly, we will explain the connections between high school and university learning, and the meaning of visualising the connections with hyperlinks. Finally, we will summarize briefly.

KIT PHYSICS NAVIGATION

Characteristics

KIT Physics Navigation has following characteristics:

・Website was built on the concept that one webpage contains one knowledge. On the webpage, mathematical expressions and figures are compactly arranged and it is easy to see by using smart phone as well as personal computer.

・Website provides learners with e-learning environment which enables them to understand the connection between high school and university learning smoothly.

・Self-adaptive e-learning website which helps learners to deepen their knowledge of physics with accessing any webpages regardless of their knowledge amount.

・ Website connects the knowledge of physics in high school and university learning with hyperlinks.

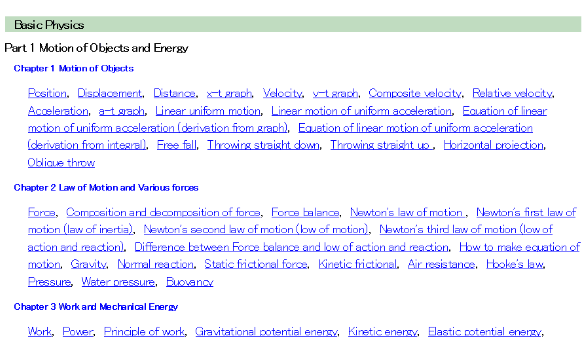
・ Website succeeded in visualizing the connections between advanced knowledge and fundamental knowledge of physics with Graph drawing .

・Website provides ICT teaching materials to promote learners' better understanding toward the motion of an object by using simulation.

・Multilingual translation is possible by using Google Translate.

Connection Between High School and University Learning in Physics

Here, we explain connection between high school and university learning in physics. Recently, we have almost finished making webpages about dynamics in high school learning, and now we are making webpages about electromagnetics in high school learning and webpages about dynamics in university learning. In Japanese high school, there are two types of physics textbooks. One is Basic Physics and another is Applied Physics. Figures 3 and 4 show the tables of contents of dynamics in Basic and Applied Physics, respectively. Figure 5 shows the hyperlink structure visualizing the connections between advanced and fundamental knowledge.



Basic Physics

Part 1 Motion of Objects and Energy

Chapter 1 Motion of Objects

Position, Displacement, Distance, x–t graph, Velocity, v–t graph, Composite velocity, Relative velocity, Acceleration, a–t graph, Linear uniform motion, Linear motion of uniform acceleration, Equation of linear motion of uniform acceleration (derivation from graph), Equation of linear motion of uniform acceleration (derivation from integral), Free fall, Throwing straight down, Throwing straight up , Horizontal projection, Oblique throw

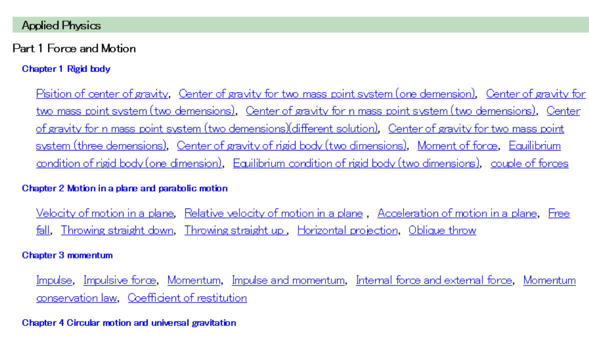
Chapter 2 Law of Motion and Various forces

Force, Composition and decomposition of force, Force balance, Newton's law of motion , Newton's first law of motion (law of inertia), Newton's second law of motion (low of motion), Newton's third law of motion (low of action and reaction), Difference between Force balance and low of action and reaction, How to make equation of motion, Gravity, Normal reaction, Static frictional force, Kinetic frictional, Air resistance, Hooke's law, Pressure, Water pressure, Buoyancy

Chapter 3 Work and Mechanical Energy

Work, Power, Principle of work, Gravitational potential energy, Kinetic energy, Elastic potential energy, Conservation law of mechanical energy

Figure 3: Dynamics in Basic Physics



Applied Physics

Part 1 Force and Motion

Chapter 1 Rigid body

Pisition of center of gravity, Center of gravity for two mass point system (one demension), Center of gravity for two mass point system (two demensions), Center of gravity for n mass point system (two demensions), Center of gravity for n mass point system (two demensions)(different solution), Center of gravity for two mass point system (three demensions), Center of gravity of rigid body (two dimensions), Moment of force, Equilibrium condition of rigid body (one dimension), Equilibrium condition of rigid body (two dimensions), couple of forces

Chapter 2 Motion in a plane and parabolic motion

Velocity of motion in a plane, Relative velocity of motion in a plane , Acceleration of motion in a plane, Free fall, Throwing straight down, Throwing straight up , Horizontal projection, Oblique throw

Chapter 3 momentum

Impulse, Impulsive force, Momentum, Impulse and momentum, Internal force and external force, Momentum conservation law, Coefficient of restitution

Chapter 4 Circular motion and universal gravitation

Uniform circular motion, Inertial force, Simple harmonic motion, Law of universal gravitation, Kepler's law

Figure 4: Dynamics in Applied Physics

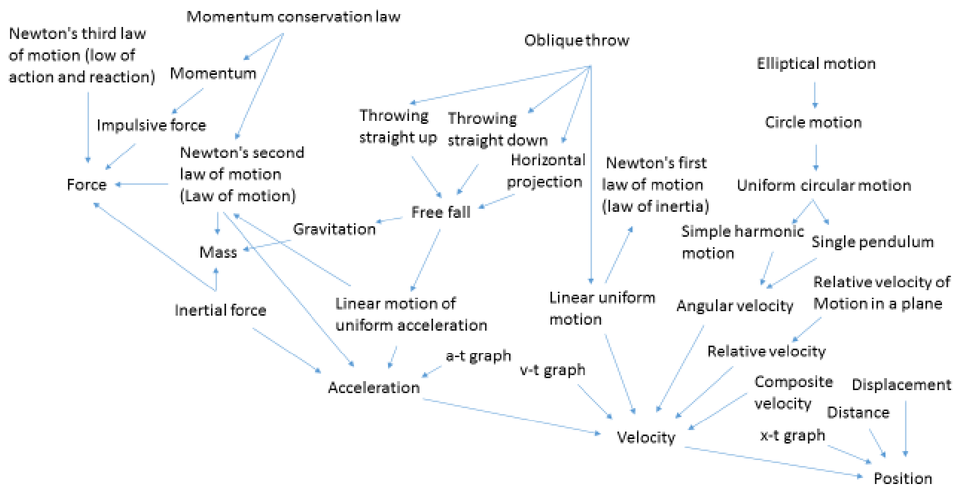


Figure 5: Hyperlink structure

Figure 6 shows graph drawing of the hyperlink structure. Here, a red node indicates the webpage learners are browsing. Green nodes indicate the knowledge of physics which is connected to the webpage learners browsed, and cyan nodes indicate knowledge of mathematics. Connections among key concepts in Standards 8 are visualized by directed edges with the directions from advanced knowledge to fundamental knowledge. We are developing a self-adaptive e-learning website that helps learners to deepen their knowledge with accessing any webpages by clicking the hyperlinks, and helps to understand the connections among knowledge. As suggested in CDIO Syllabus, ‘‘Modern engineering professions often rely on a necessary core Knowledge of Underlying Sciences’’, we will cover all of core STEM Knowledge in KIT Navigations in the future.

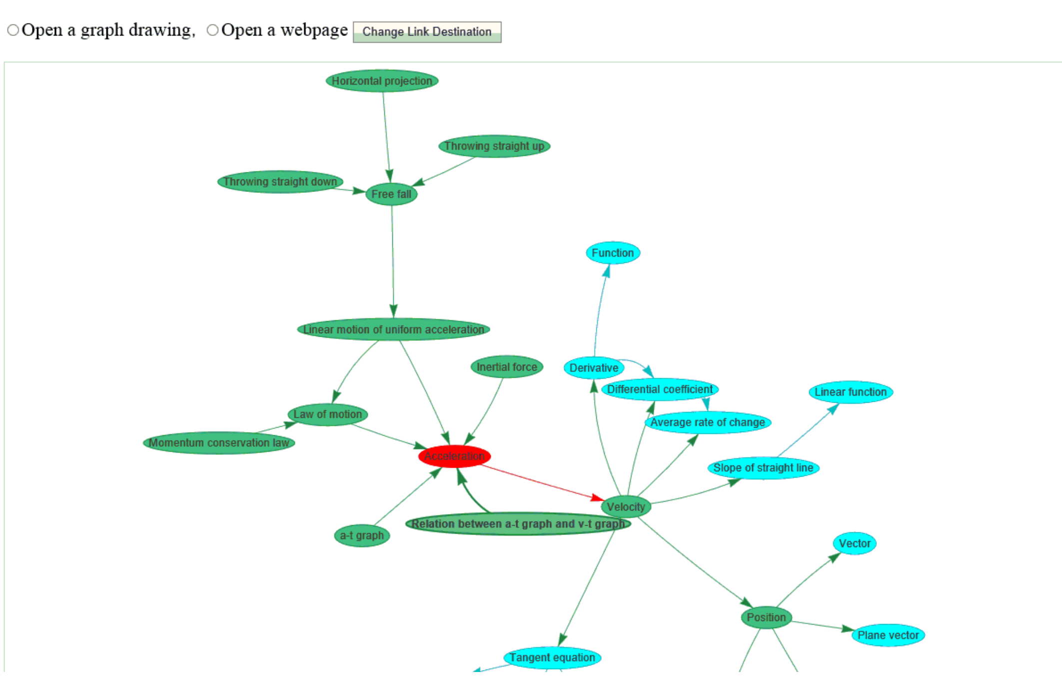


Figure 6: Graph Drawing

A few years ago, after the lecture of physics in university, a student came to one of the authors and said, ``I do not understand the meaning of calculus.'' For him, the author explained its meaning by using figs. 7 to 9 as follows. An equation of position for linear motion of uniform acceleration is derived by calculating the area of a trapezoid in v-t graph in high school in fig. 8 and is also derived by integrating an equation of velocity in university in fig. 9. Here, initial condition is given. On the contrary, the equation of velocity is obtained by calculating the slop of a tangent line in x- t graph in high school and is obtained by differentiating the equation of position in university.

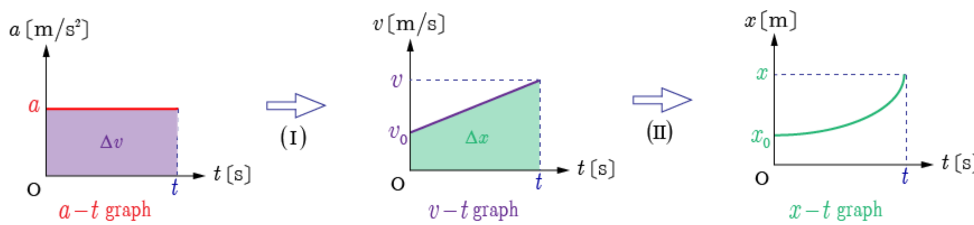


Figure 7: a-t, v-t, x-t graphs for linear motion of uniform acceleration

When the object is performing constant linear motion , the acceleration of the object is constant ($a = \text{const}$).

Initial condition: time $t = 0\,\text{s}$ Speed at $v(0) = v_0[\text{m/s}]$, Position $x(0) = x_0[\text{m}]$.

(I) $a-t$ The area of the light blue part of the graph is $0 \sim t$ Increase of speed $\Delta v[\text{m/s}]$ Indicating

$$\Delta v = at$$

Therefore, the speed is

$$v = v_0 + \Delta v = v_0 + at$$

(II) $v-t$ The area of the light blue part of the graph is $0 \sim t$ Increase of position $\Delta x[\text{m}]$ Indicating

$$\Delta x = \frac{v + v_0}{2}t = \frac{v_0 + at + v_0}{2}t = v_0 t + \frac{1}{2}at^2$$

Therefore, the position is

$$x = x_0 + \Delta x = x_0 + v_0 t + \frac{1}{2}at^2$$

Figure 8: A derivation in high school

(I) speed $v[\text{m/s}]$ Can be obtained by integrating as follows.

$$v = \int a\,dt = at + C_1$$

When $t = 0\,\text{s}$, $v = v_0[\text{m/s}]$ To the above equation $C_1 = v_0$ Is obtained.

Therefore speed $v[\text{m/s}]$ Is

$$v = v_0 + at$$

(II) position $x[\text{m}]$ Can be obtained by integrating as follows.

$$x = \int v\,dt = v_0 t + \frac{1}{2}at^2 + C_2$$

When $t = 0\,\text{s}$, $x = x_0[\text{m}]$ To the above equation $C_2 = x_0$ Is obtained.

Thus position $x[\text{m}]$ Is

$$x = x_0 + v_0 t + \frac{1}{2}at^2$$

Figure 9: A derivation in university

After the explanation, the student told the author ``for the first time, I understood the meaning of calculus.'' At that time, the author thought that it is very significant for students to clarify the connection between high school and university concepts. There is a certain gap between high school and university concepts. If we can fill such a gap by connecting knowledge in high school and university learning with hyperlinks and graph drawings, then it will help learners to have essential understanding, not just memorizing a piece of knowledge. Furthermore, learners will be able to derive a fundamental equation easily by understanding a definition on the website. Such a learning method leads learners to turn their bad feelings for physics into good one. Thus we visualized the connections between high school and university concepts with hyperlinks. It is very important that instructors teach the connections among key concepts clearly in lecture as is pointed out in Standard 8. The website which emphasizing the connections between high school and university concept with graph drawings is very useful for both of students and instructors, and it will also make a contribution to improve teaching skills of instructors in Standard 10.

SUMMARY

As pointed out in CDIO Syllabus and CDIO Standard, it is essential for engineers to learn fundamental scientific knowledge as the basis of CDIO and to understand how to connect pieces of fragmental knowledge they have with each other. We have been developing the self-adaptive e-learning website which enables learners to connect advanced knowledge to fundamental knowledge as well as that of high school and university learning with accessing any webpages. In graph drawings, nodes indicate a piece of knowledge, and directed edges indicate the connections between advanced and fundamental knowledge. Our website enables engineering students to acquire fundamental knowledge as the basis of CDIO and understand the connections between them efficiently.

As a future assignment, we are considering to develop another self-adaptive e-learning website in field of electromagnetics, wave mechanics, optics, heat mechanics, etc., to enhance the STEM environment. Furthermore, we will confirm the efficacy of KIT physics navigation to the students.

ACKNOWLEDGEMENT

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BIOGRAPHICAL INFORMATION

Tomoshige Kudo is an Assistant Professor in Academic Foundations Programs at Kanazawa Institute of Technology. His current research focuses on Peer Instruction lecture in mathematics and physics. He develops self-adaptive e-learning website, ''KIT Physics Navigation'', and researches foundation of quantum mechanics.

Keita Nishioka is an Assistant Professor in Academic Foundations Programs at Kanazawa Institute of Technology. He develops self-adaptive e-learning website, ''KIT Physics Navigation'', and researches theoretical condensed matter.

Akira Nakamura is a Professor in Academic Foundations Programs at Kanazawa Institute of Technology. His current research focuses on knowledge structure of STEM (Science, Technology, Engineering, Mathematics) in self-adaptive e-learning website of STEM.

Corresponding author

Dr. Tomoshige Kudo
Kanazawa Institute of Technology
7-1 Ohgigaoka, Nonoichi, Ishikawa
921-8501, Japan
+81-76-248-1183
kudo@neptune.kanazawa-it.ac.jp

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EXPERIENCES ON A CDIO INTRODUCTORY PROJECT TRANSFER TO A NEW TEACHER

Katriina Schrey-Niemenmaa, Antti K. Piironen

Metropolia University of Applied Sciences, Finland

ABSTRACT

An introductory project parallel with basic studies of mathematics, physics and electronics have been run on the second half of fall semester of electrical engineering degree programme. The learning outcomes are set to emphasize soft skill such as project management, team working, basic finance, time lining, marketing, and communications skills. Additionally to those skills, CDIO ideas including the importance of engineering ethics and responsibility of the sustainable development are highlighted.That project is using LEGO® Mindstorm robots as experiment tools. In the beginning the students are conceiving the challenges - how can they make customers happy with the available things. Secondly they design and plan the products both the construction and functionality, including programming. Finally the students operate the robot until it is cut into parts again and the box of materials returned. The first year project has been developed and fine tuned by the same teachers over several years. However, the fall 2017 change of teacher for a part of groups was evident, and therefore an interesting question arose: how well the the successor likes to follow the design and concept, or does the new teacher recreate the course again? In this paper we are presenting a case study on transferring a pedagogical concept when the teacher changes.

KEYWORDS

Integrated curriculum, introductory project, active learning, Standards: 3, 4, 5, 6, 7, 8, 10

INTRODUCTION

In Finland the B.Eng. curriculum in the Universities of Applied Sciences is planned to take 4-years. Programmes are based on secondary high school education or vocational technical education. During the first year in the University the students need to be able to strengthen the competences that are weak after their previous education. The students coming from senior high school typically master more theoretical things like mathematics and physics but have very little experience of engineering. On the other hand the students with vocational education have more experience and understanding about the practical technical issues. The diversity between the students becomes even greater as several of them have already some years of work experience. To give a solid foundation for the engineering studies for such diverse groups of students is a serious challenge. This challenge gives also a great opportunity to benefit from joint learning from each other's in small groups. During the following years students are deepening their knowledge on sciences and engineering parallel with other competences needed.

The engineering programmes of Metropolia University of Applied Sciences are strongly empathizing the CDIO model (Karhu, 2010); Schrey-Niemenmaa et al., 2010). Engineering curricula went through a major overhaul few years back, when practically all degree programmes designed the first year studies to employ integrated, problem- and project-based learning, combined with co-teaching methodology (Schrey-Niemenmaa & Yli-Pentti, 2011). There are plenty of evidence that the chosen methodology decreased the first year drop-out rate drastically indicating that the students' engagement to engineering studies improved (Karhu et al., 2010). The enhancement of the programmes has been based on continuous self-evaluation and cross-sparring with critical friends from different other universities and internally. The method is developed in joint projects with over ten universities around Europe. The system is completed in an ERASMUS+ project which finished 2016. This kind of systematic work has proved to be very beneficial and effective (Schrey-Niemenmaa et al., 2016).

As an implementation of the new curriculum, the Electronics Degree Programme developed an introductory project integrating basic studies of mathematics, physics. The project is scheduled at the second half of fall semester. The learning outcomes are set to emphasize soft skill such as project management, team working, basic finance, time lining, marketing, and communications skills. Additionally, to those skills, CDIO Standards 3-8 including the importance of engineering ethics and responsibility of the sustainable development are highlighted (Crawley et al., 2014).

The introductory project was developed over several years by the same group of teachers. While a static situation enabled fine tuning of the concept, it was evident that the day would come when another teacher would take over the course implementation. Therefore, an interesting question arises: how well the the successor follows the design and concept, or does the new teacher recreate the course again? In this paper we are presenting a case study on the challenges of transferring a pedagogical concept when the teacher changes. Students' learning results were compared and both teachers were interviewed and their observations were compared.

INTRODUCTORY PROJECT

The first year curriculum is divided into four modules - each of which takes 8 weeks. The students are evaluated from the modules with only one grade. That means they need to pass all the elements to pass the course. The required elements are typically taught by a group of 5 teachers. The teachers are cooperating and trying to add value to each other's content, which also enhances their teaching competences (CDIO Standard 10).

An introductory project is a vital part of the second module in the degree programme of electrical engineering. The learning objectives of the project are set in project management (including scheduling, budgeting, communication, risk analysis, self -evaluation etc.), team building and group working, presentations, basics of marketing, finding information, basics of building, and coding additionally to self- and group evaluation and feedback.

In the beginning of the course students are forming groups of 4 people. In some classes the students are allowed to form the groups themselves and in some classes the teacher have made the decision. If the students can form the groups themselves they usually work with their friends and thus do not experience that much of “tolerating difficult colleague” or other challenging surprises. Sometime they then can even benefit from the pleasant atmosphere and can concentrate on other learning outcomes. However, in earlier studies we have found no significant differences due to method of group forming (Piironen et al., 2009).

The first task for the group is to collect a box of LEGO® Mindstorms and explore what is in the box. The content enables the building of a robot with different features. Then the group needs to start to search for information - what can be done with the content. Additionally they can decide what extra parts or materials they want to use. There are available a big box of spare parts from robots and from other LEGO® building series. Furthermore the group is allowed to bring in whatever they manage to get from elsewhere.

Next step is to write a project plan that covers all the features of the learning outcomes. Additionally the tasks the plan needs to include are:

- Create a story of your robot to sell it to your customer - introduce the story in a 1 minute presentation to your potential customers (other students in the class). After the presentations the most attractive robot of the class is chosen in the first competition.
- How to manage the track of the second competition. The track is introduced after the 1st competition. It is about 4 meters long black line in a white background including a wall, where the robot needs find a detour. After passing the wall the robot needs to find the black line again and follow it until it hits a blue spot. In the second competition the time of running the track is measured and the quickest one is the winner.
- Finally the robots need to be undone, original parts returned to the box and other parts in their places.
-

At the end of the project the final report needs to be done. That report includes a self and group evaluation.

During the whole project the groups are following up their advancement with a diary. The diary includes notes of participation of the members, challenges they have met, learning points, and major inventions.

The evaluation of the project gives maximum 24 points which is 20% of the whole module. The points are granted:

- 6 points from project plan
- 2 points from the 1st competition including marketing speech
- 2 points from the 2nd competition
- 8 points from final report
- 2 points self- and group evaluation
- 4 points from the diaries
-

This division of the points is giving the students a clear message how important the different parts are. Especially the emphasis is given to the joint support to other students and constructive attitude. That includes also the responsibility of reporting internally in the group about schedules and unexpected problems. Failures in programming or other things are accepted - only a good analysis of the reasons is needed.

CREATIVITY OR STANDARDISATION?

In Finland one characteristic factor of teaching in all levels is the freedom of the teacher. Learning outcomes are defined nationally for secondary level of education and by the University for Tertiary Education. The teachers, lecturers and professors are mostly allowed to decide their way of reaching learning outcomes in their own courses. That freedom leads to high commitment and responsibility to the teacher. Furthermore it motivates for continuous development of the execution of the courses.

As a teacher gets a new course to take care of it demands quite an effort to design. In that case it might be a smoother way to get ready instructions for the first turn and according to the experiences then renew the course gradually. Especially the need for instructions are required if a teacher gets with a short notice a course for instance in case when the standing teacher is temporary prevented.

Standardisation of the first year project course means clear description of:

- different steps of the course including schedule
- slide sets for teachers' lectures
- format for students' written assignments
- description of the evaluated non-written assignments

In the picture 1 is an example of the course plan. That kind of format can easily be adapted to the new groups.

Week	Tuesday	Friday	Obs
43	Lecture: what it means to be an engineer? Which competencies and skills are needed, what are the expectations of working life? How to learn, project based learning, CDIO, basics of project management. Starting the project	Conceiving the project Group Work	
44	Building, constructing, Conceiving the project, project plan	Building, constructing, Conceiving the project, project plan; Independently	
45	Building, constructing, Group Work Independently	Building, constructing, Group Work	Download the project plan latest on Wednesday
46	Feedback from project plan	Competition 1 Constructing, programming,	
47	Constructing, programming,	Constructing, programming, Independently	You can see the track on Nov 21
48	Constructing, programming	Constructing, programming	
49	Constructing, programming,	Competition 2 on the 8th December in room 504 (perhaps already on Thursday?)	
50	Undo the robot, count the parts, return the extra robot parts to "spare part box" and other extra legos to the big brown box. Return the cleaned robot box.	Finalize the reports	Download the final report latest 21.12.

Figure 1. Plan for the 8 week project course

Additionally the special occasions are needing an exact guideline as otherwise the temporary teacher might have difficulties on keeping in schedule, getting the expected outcomes and finalising the operate stage - recycle the materials for the future use. In the Figure 2 there is an example of the guideline for the final competition. That guideline tries to guarantee that the students have a fair competition, all the groups get their results and the Lego-boxes will really remain usable in the future.

Final steps of the project course:

- Recycle the lego-box:
  - o Undo the robot, count the parts, add missing parts, return the extra parts to the “spare part boxes”;
    - § robot parts to plastic box
    - § extra motors and sensors to the separate plastic box
    - § other parts to the cartoon box
    - § broken parts to the shown box
  - o fill the report sheet - leave in the box the report and the list of names.
  - o after the teacher have accepted the box, replace it in the cupboard.
- Have a team discussion about the team work, roles and learning outcomes of the course. During the discussion and give feedback to each other and fill in the group- and self-evaluation form. Return the form individually.
- Finalise the “final report”, please note that the report covers the whole project of 8 weeks. Pay attention to the learning outcomes, risk analysis, project management etc. Add photos and links to videos to the report. The technical attachment might include screenshots of the used code. One report from the team.
- Fill in the diary and submit - one final diary from the team.

Figure 2. An example of the guideline for the end of the project course

RESULTS AND DISCUSSION

The introductory project course was developed over several years by a teacher, who is a senior adopter of the CDIO principles in Metropolia. The new teacher in charge of the course was less familiar with CDIO. Furthermore, the situation was quite challenging because the teaching resource management was done late and the new teacher did not get sufficient time to prepare his own adaptation and plans in advance. The current and previous teachers met briefly few times to transfer material, concept, timing, and other necessary information to carry out the implementation.

The standardisation helped a lot and made it possible to offer the students the course despite the absence of the previous teacher. The new teacher mentioned that the standardization of the course did not limit at all his pedagogy, but quite the opposite released him from planning the course over again, and instead he could concentrate his efforts on teaching practices. Detailed instructions on implementation were considered very valuable in use.

When comparing the student’s learning outcomes we cannot see any significant differences. Student groups did robots which performed similarly the same tests as previous student groups. The robots were also quite equally innovative as earlier. The drop-out rate remained negligible, and students' grades based on achieving the learning objectives sustained very good values.

Student feedback remained positive and constructive. Some students felt they would have needed more guidance on planning the project and writing the project report, which was also observed by both new and old teacher. On the other hand, we also need to remember that this is an introductory project, and the students will get more practice throughout the rest of their studies.

CONCLUSIONS

An introductory project developed and fine tuned by a teacher promoting CDIO was standardised and transferred to another teacher with almost none experience on the CDIO principles. The course standard was documented in detail, which allowed the new teacher to focus on teaching practices instead of detailed preparation of the course. The learning results did not show any significant differences compared to previous year's results. Still the motivation/introductory lecture in the beginning of the course was given by the teacher who had much experience of CDIO adaptation. That gave confidence to the temporary teacher and guaranteed the right message to the students. The students results documented were in the same range as they used to be although the feelings have no measurements that one can scientifically produce evidence. In our opinion, there is a growing need for more engineering education research in Europe on transferability of CDIO- based teaching modules (Ekström, 2017).

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BIOGRAPHICAL INFORMATION

Antti K. Piironen, Ph.D. is a Principal Lecturer of Smart Systems Engineering in the School of ICT at Metropolia University of Applied Sciences. He collaborates regularly with universities in Europe on topics related to joint courses, teacher exchange, and curriculum design. His current scholarly activities focus on the providing professional ICT engineering education using mixture of modern and traditional teaching tools and methods.

Katriina Schrey-Niemenmaa, Lis.Tech.Sc is a Senior Lecturer at Metropolia University of Applied Sciences. She is an active collaborator in national and international organisations in the area of developing engineering education (IACEE, SEFI, CDIO, TEK etc.). Her scholarly activities focus on the attractiveness and quality of engineering education.

Corresponding author

Dr. Antti K. Piironen
Metropolia University of Applied Sciences
Vanha maantie 6
FI-02650, Finland
+358-40-555-2871
antti.piironen@metropolia.fi

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INTEGRATING SUSTAINABILITY IN ACADEMIC CDIO SUBJECTS: A REVIEW AFTER THREE YEARS OF EXPERIENCE

Ángel Uruburu, Ana Moreno-Romero, Ruth Carrasco-Gallego, Rafael Borge

Escuela Técnica Superior de Ingenieros Industriales, Universidad Politécnica de Madrid

Julio Lumbreras

UPM Director for North America, Visiting Scholar at the Harvard Kennedy School

Rafael Miñano

Escuela Técnica Superior de Ingeniería de Sistemas Informáticos, Universidad Politécnica de Madrid

Ángel Uruburu ORCID Id.: 0000-0002-1663-3924

ABSTRACT

We present in this study the results and reflections about the implementation of a specific teaching-learning methodology that has been designed to incorporate sustainability aspects in "INGENIA" projects. These 12 ECTS-compulsory subjects are taught following the CDIO standards, according to which the students must develop a somehow innovative product or service from the conception and design to the implementation and operation. After three academic periods, the study discusses how our strategy has been quite satisfactory for students to strengthen their competences related to sustainability. Results firstly show that the students value positively the experience, having gained a greater awareness on sustainability issues and expanded its vision on the complexity of engineering activity. Secondly, from the point of view of the instructors, the designed methodology successfully meets the objectives previously defined. Thirdly, some difficulties encountered during the action-research period have led to the implementation to some modifications in the methodology, mainly oriented to a better adaptation to very different and heterogeneous projects. In conclusion, it is highlighted that the integration of sustainability in CDIO subjects is a complex task, which needs to overcome some difficulties, those specifically related to the intrinsic particularities of the development of each project and the coordination of multidisciplinary teams of professors.

KEYWORDS

Sustainability, Social Responsibility, Professional Responsibility, Ethics, Project-based courses, Standards 2, 3, 6, 7, 9, 11

INTRODUCTION

Engineering programs are increasingly recognizing the understanding of the responsibilities of the professional engineer in society, and the ability to analyse ethical, societal and environmental aspects of engineering activities as important goals to ensure in graduate students' profile (ABET, 2015; CEAB, 2017). The CDIO Syllabus 2.0 already includes ethical and social responsibility aspects and sustainability criteria for each one of the lifecycle stages (CDIO, 2011) and, recently, Malmqvist et al. (2017) included *sustainable development* as an optional CDIO standard in their proposal presented at the last International CDIO Conference.

In the last decade, many authors have explained their experiences about the integration of sustainability (Binder et al., 2017; Enelund et al., 2012; Hussmann et al., 2010; Silja et al., 2011; Wedel et al., 2008) or ethics (Augusto et al., 2012; Lundqvist, 2016; Palm & Törnqvist, 2015) into the context of CDIO engineering education. In the same line, Miñano et al. (2016) and Borge et al. (2017) presented in past CDIO Conferences the work developed in the Escuela Técnica Superior de Ingenieros Industriales, Universidad Politécnica de Madrid (ETSII-UPM).

In accordance with the mission of the ETSII-UPM, it is essential that its students become ethical, professionally aware and responsible for the implications of their activity, promoting sustainable development (ETSII-UPM, 2016). To achieve this goal, the work on transversal competences has been strengthened and the number of subjects that promote sustainability issues has been increased in the curricula. ETSII is accredited by the Accreditation Board for Engineering and Technology (ABET), which includes three learning outcomes that are directly related to sustainability: c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability; f) an understanding of professional and ethical responsibility; and h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context (ABET, 2015).

Using this competency framework, some project-based learning (PBL) innovations began to follow the CDIO methodology (Díaz Lantada et al., 2014) and become a reference to blend ABET and CDIO proposals. The new master's Degree in Industrial Engineering is the program in which the above outcomes were outlined as one of the main priorities of the overall curricula including a new innovative set of PBL courses denominated "INGENIA", whose name comes from "ingeniar" (to provide ingenious solutions) and "ingeniero" (engineer). All INGENIA courses have an analogous structure; primarily aiming at the acquisition of professional outcomes not only related to sustainability but also with the ability to design, implement and operate engineering systems, as well as creativity, teamwork and communication skills. Every subject is directly linked to the different ETSII-UPM majors (Lumbreras et al., 2015).

The teaching-learning strategy adopted fits to CDIO standards, such as the intensive use of supporting software, prototyping technologies and testing facilities at different labs, enabling the instructors to fulfil adequately all the CDIO steps, from the conception and design, to the implementation and operation.

In this paper we discuss the most relevant results of the implementation of the methodology after three years of experience and the new challenges to cope by the instructors for future

INGENIA courses. Our conclusions are based on the annual students' assessment of the learning outcomes and the teachers' reflections about their work.

METHODOLOGY

The context: INGENIA/CDIO Courses

INGENIA courses are compulsory in the master's Degree in Industrial Engineering Program These subjects are 12 European Credit Transfer System (ECTS) equivalent, which correspond to a student workload between 300 to 360 hours, distributed along two semesters with the following structure: 120 hours of class work plus 180-240 hours of personal student work usually organized in teamwork. Class work of the subjects is structured in three modules:

- Module A (Technical): 30 hours dedicated to adapting basic theoretical knowledge derived from other subjects to those directly related with the project, and a second set of 60 hours is devoted to practical work in the lab, with professor supervised sessions.
- Module B (Transversal skills): 15 hours for workshops on teamwork, communication and creativity skills and techniques.
- Module C (Sustainability): 15h for lectures and workshops about social responsibility issues such as environmental and social impact, ethics and professional responsibility, health & safety, intellectual property, etc.

Table 1. INGENIA learning outcomes correlated with CDIO Syllabus 2.0.

	INGENIA learning outcomes		
CDIO Syllabus 2.0	Module A (Technical) ABET (b) (c)	Module B (Skills) ABET (d) (g) + Creativity	Module C (Sustainability) ABET(c) (f) (h)
2.2 Experimentation, Investigation and Knowledge Discovery	■		
2.3 System Thinking	░		░
2.4.3 Creative Thinking		▓	
2.5 Ethics, Equity and Other Responsibilities			■
3.1 Teamwork		■	
3.2 Communications		■	
4.1 External, Societal and Environmental Context	░		■
4.2 Enterprise and Business Context	░		■
4.3 Conceiving, Systems Engineering and Management	■		
Environmental needs. Ethical, social, environmental, legal and regulatory influences. Risks and alternatives			▓
4.4 Designing	■		
4.4.6 Design for Sustainability, Safety, Aesthetics, Operability and Other Objectives			▓
4.5 Implementing	░		
4.5.1 Designing a Sustainable Implementation Process.			▓
4.6 Operating	░		
4.6.1 Designing and Optimizing Sustainable and Safe Operations			▓

■	Strong correlation, according to CDIO-ABET correlation (CDIO, 2011)
░	Good correlation, according to CDIO-ABET correlation (CDIO, 2011)
▓	Strong correlation (own criterion)

These lectures, practical sessions, seminars and workshops, are distributed along the 28 weeks of the two semesters of the first year, resulting in 5 hours per week of lectures or practical sessions in the regular schedule of students. The relation of each module with the CDIO Syllabus can be seen in the above Table 1.

Research Design

To carry out the research on the integration of sustainability competencies in the INGENIA/CDIO subjects, we have opted for an action-research methodology that allows to plan, act, observe and reflect more carefully, systematically and rigorously than we usually do in everyday teaching work (Cohen et al., 2011). Based on the previous bibliographic research work, the results obtained in previous experiences and a joint reflection with the team of professors of the sustainability module, a first work proposal was elaborated, which was implemented in the 2014-15 academic year. Since then, the process has been iterated for three years.

For this purpose, various evaluation questionnaires (pre and post) were designed, which allowed to obtain relevant information (quantitative and qualitative) on the progress of the students in the acquisition of competences and on the teaching-learning process itself.

Throughout each course, the team of professors had regular meetings in order to share the evolution of the course, reflect on it and work on the improvements to be implemented. Likewise, specific sessions were held at the end of each course to assess the results of the evaluations and plan the next course.

Teaching Methodology

Sustainability is a key aspect that INGENIA students must carefully consider throughout the four CDIO steps. In this sense the initiative requires a comprehensive methodology to be systematically used in all the projects, but flexible enough to be adapted and oriented to the specific social, environmental, economic, strategic and ethical aspects of each of them. The CDIO practical approach enables to consider those issues by a systematic exploration of all lifecycle phases. It provides a holistic view needed to avoid environmental bias and to deal with complexity (Cheah, 2014). Furthermore, we intend to send to our students the message, supported by several authors (Palm & Törnqvist, 2015, Crawley et al., 2008), that integrating ethical assessment, emphatic design, and social and environmental criteria strengthen the final product.

Our conceptual model considers the three classical dimensions of sustainability (economic, environmental and social), emphasizing the essential fact that these dimensions must be deeply grounded on the ethical and professional responsibility issues that may be relevant to each specific project. We add a strategic dimension that must always be considered in every phase of the project, by means of identifying its basic “why/what for”, their main differentiation characteristics, or how the long-term shared-value creation will be created in its development. These aspects cannot be studied separately, that’s why our framework also includes the relationships with the different stakeholders that may be affected by the technology/service/artefact developed in the project. These are the foundations of our methodology, characterized in Figure 1 (Miñano et al., 2016).

At the beginning of the course, an opening lecture is given to all the INGENIA courses’ students together. We introduce our conceptual model, revise the concept of sustainability, the principles of engineering ethics, and present briefly some categories of both social and environmental impacts. Throughout the two semesters, different workshops and tutorials (12 hours) for each INGENIA course were scheduled. Two faculty members worked closely with the students with the specific objective of integrating all the sustainability aspects into their project.

Key guidelines for dealing with this holistic integration were developed, establishing four phases to carry out the works: identification and selection of the relevant issues, deep analysis of specific social and environmental impacts, the practical integration into the product and a final reflection. As it was explained in detail by Miñano et al. (2016), this method is inspired in several methodologies like Life Cycle Assessment (Curran, 1996) and Social Life Cycle Analysis (Benoît & Mazijn, 2009), Value Sensitive Design (Cummings, 2006), ethical assessment of technology (Wright, 2011) and ISO standards 14000 and 26000.

As a deliverable, the teams must prepare a document which structure is provided beforehand, synthesizing their analysis, reflections and actions on the final product. The report is evaluated by the instructors and it represents 12,5% of the final score of the INGENIA course.

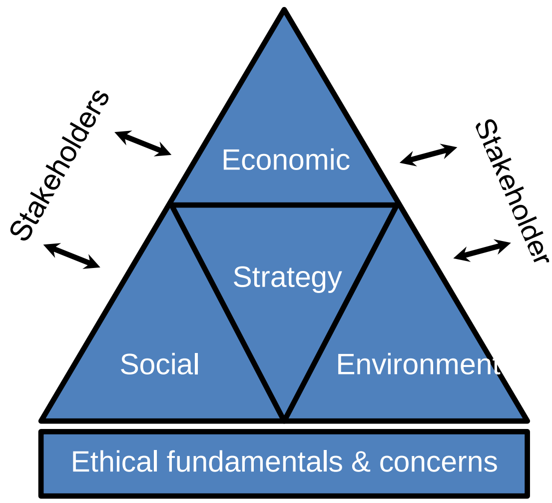

Figure 1. Framework for integrating sustainability and ethics in the INGENIA subjects.

RESULTS

The experience developed during these courses has been analysed from two perspectives: a) the progress of the students in relation to their sustainability competences, and b) the teaching-learning process itself. To study the progress in the acquisition of sustainability competences, two questionnaires were designed: the first one about knowledge on professional responsibility and impacts of engineering, and the second one about self-perception of skills for the integration of sustainability in projects. Both individual questionnaires were completed by the students at the beginning and end of the 2014-15 and 2015-16 courses.

To assess the teaching-learning process, the meetings held between the teachers of the module and the students' questionnaires about the final evaluation of the courses 2014-15, 2015-16 and 2016-17 were considered.

Questionnaire on knowledge on professional responsibility and impacts of engineering

In this questionnaire, the students had to answer open questions about aspects of professional ethics:

P1 Indicate the values and/or ethical principles that you consider fundamental in relation to professional practice in the field of engineering (4 maximum).

P2 Do you know any deontological code related to engineering? If yes, indicate which one.

And on knowledge about relevant impacts of engineering in a global context (3 maximum):

P3. Negative environmental impacts

P4 Positive environmental impacts

P5 Negative social impacts

P6 Positive social impacts.

Paired samples were considered (n = 65 in the 2014-15 academic year and n = 141 in the 2015-16 academic year) with a pre and post-test.

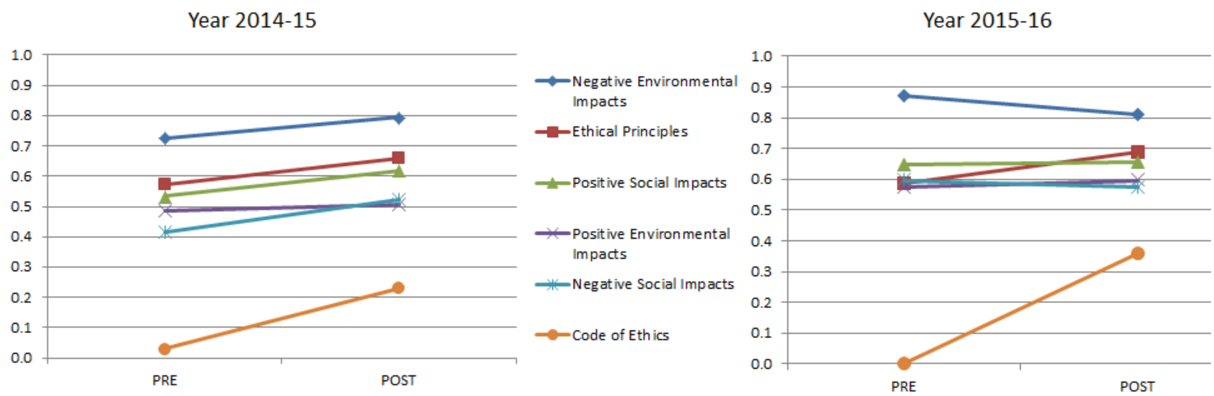

Figure 2. Comparison (pre-post) of the number of valid answers about knowledge of professional responsibility and impacts of engineering (average adjusted to 1).

In the 2014-15 academic year, quite satisfactory results were obtained, with significant improvements in almost all the items. In the 2015-16 course the initial results were much better than in the previous academic year, and the final results are also better than in the 2014-15. However, only significant improvements were observed related to the ethical aspects (P1 and P2), showing worse results in negative impacts items (P3 and P5).

Questionnaire on self-perception of skills for the integration of sustainability in projects

In the second questionnaire, we ask the students to rate on a 0-5 scale their abilities to identify impacts (environmental, and social), perform an analysis and assess them (environmental, and social), and to introduce changes in projects that optimize those impacts (minimize negative impacts, and promote positive impacts), following CDIO steps. Paired samples were also considered (n = 59 in the 2014-15 academic year and n = 143 in the 2015-16 academic year)-.

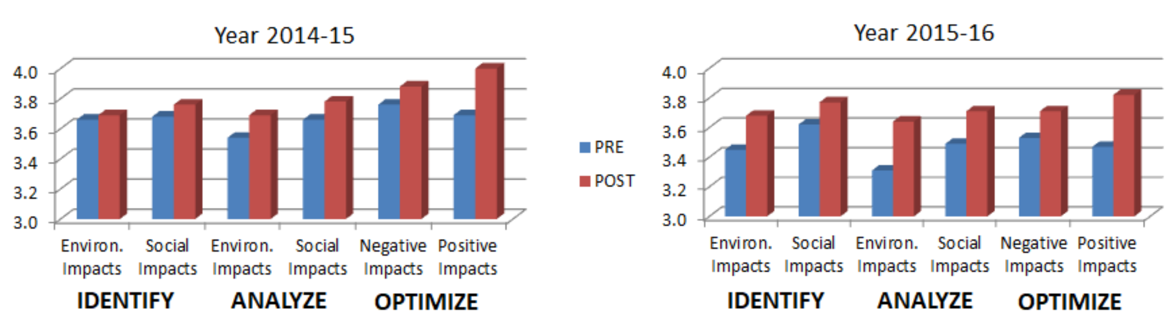

Figure 3. Students' self-perception about their capacities for integrating sustainability criteria in engineering projects (average over a 0-5 rank).

In general, the students have a very positive perception of their abilities. The median in almost all variables is 4, which indicates that more than 50% of students have a good perception of their abilities in these aspects, and the first quartile is 3 in all questions (more than 75% is rated with a score greater than or equal to 3).

All the aspects improve after having studied the INGENIA/CDIO subjects, being all of them statistically significant (95%) in the course 15-16 (the size of the sample was greater). The most relevant improvement is in "the ability to enhance positive impacts". The other aspect that improves much is the "analysis of environmental impacts", in which they perceived themselves less conscious. This makes the differences between items decrease with respect to those observed at the beginning of the course, which is a positive data on the influence of the work developed in the sustainability module.

Questionnaire on teaching-learning process

In order to obtain information on the assessment of the students about the teaching-learning process, quantitative data (numerical assessment from 1 to 5 on different aspects) and qualitative data (open questions on the most positive, the most negative and proposals for improvement) were collected.

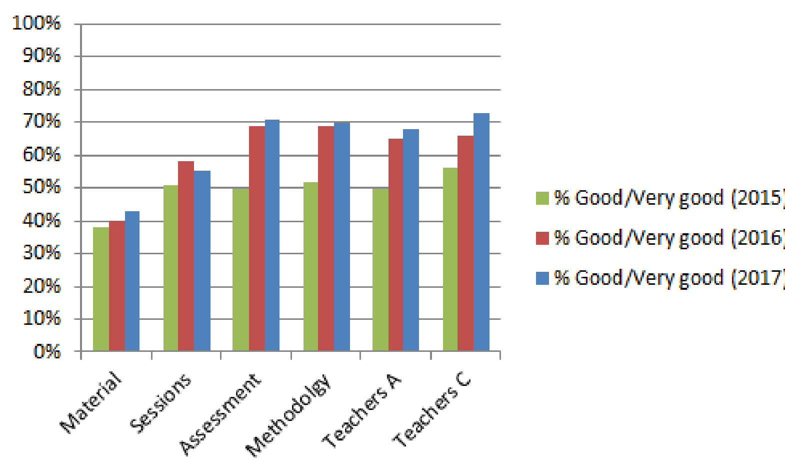

Figure 4. Students' assessment of the teaching process of the sustainability module (C) Evolution along three years.

The quantitative results show that the aspects most valued by the students were the support of the teaching staff, both module C (sustainability) and module A (technical), and the global teaching-assessment methodology. In the last course, more than two thirds of the students rated the performance in these aspects as "good" or "very good". It is also observed that the results have been improving with the courses, especially in these areas (in the first course evaluated, the percentage of students who valued it positively was around 50%).

Regarding the aspects that the students consider to be more positive, the knowledge on skills and attitudes learned have been the most mentioned in all the courses. In the first year, more references to more practical learning appeared, especially in the environmental dimension ("learning the Life-cycle Assessment methodology"), and in the subsequent courses more frequent comments on the identification and analysis of impacts appear, and their application in specific cases.

On the other hand, there are two aspects that, according to the students' opinion, should be improved. The first issue is related to the back-up documents provided for their individual homework (more than half of the students consider it to be fair or poor), while the second refers to the scheduling and development of some lectures. Nevertheless, it is relevant that in almost all aspects a positive evolution can be observed throughout the three courses.

DISCUSSION AND CONCLUSIONS

As a result of this work of analysis and reflection on the experience of these three years, some conclusions have been synthesized. In the first place, the general perception of the teaching staff is that the experience has reached a good level of maturity, so that, maintaining the proposed conceptual model and the basic methodological structure, we should continue working by adapting it to the specific circumstances of each of the different INGENIA/CDIO subjects.

Secondly, the institution has become aware that the experience takes place in a complex and diverse context. This is mainly due to the high academic requirement of the master's degree in which the INGENIA subjects are framed, different profiles and motivations of the students, time restrictions, great diversity of subjects and orientation of the INGENIA subjects, teacher rotation and the diversity of profiles in the teaching staff, among other causes.

Thirdly, this has led us to readjust the teaching objectives, synthesizing the essentials, in order to adapt them to the reality of the academic context in which we work. The fundamental objective will be to convey the importance of considering the aspects of sustainability into the development of a project and all its possible implications, assuming its complexity and diversity of dimensions. As a secondary objective, it would be necessary to acquire specific skills and/or techniques, assuming that the scope of the sustainability module in the INGENIA subjects is not enough to cover all the technical aspects of its different dimensions with all rigor.

In this sense, our conceptual model has proved to be useful because of the global vision it provides, and to make present important aspects of professional practice that are not usually addressed in academic training. The consideration of stakeholders is something that the students are not used to, and it is new to them. The ethical aspects have been one of the areas in which a significant improvement has been identified, as well as in the self-perception that they have of promoting positive impacts, related to a strategic vision oriented to the creation of shared value.

Moreover, this global vision and a greater awareness among students of the importance of sustainability as part of an engineering project, are among the results that they consider to be the most positive of the work developed in the module. Another aspect that has stood out in the evaluations is the usefulness of the acquired learning concepts, being these very diverse, from concrete techniques of environmental analysis (life-cycle assessment), to abilities to identify possible impacts or groups of interest.

Finally, the most important challenge we are currently facing is to achieve a better adaptation to circumstances of each INGENIA/CDIO subject, so that sustainability is not perceived as something separate or without connection to the project to be developed. With this objective in mind, it has been decided to improve the coordination among the professors of al the modules -not only the sustainability one, in order to plan the specific sessions at the most appropriate times and select the contents and tasks that better facilitates the integration of sustainability criteria to add value to the project.

We consider that the experience developed during the last three years has been very fruitful, consolidating the inclusion of sustainability as something of vital importance in the development of technological projects under CDIO standards, and creating a methodological framework on which to continue advancing and improving the training of future engineering professionals.

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BIOGRAPHICAL INFORMATION

Dr. Ángel Uruburu Colsa is Associate Professor of Engineering Projects in the Department of Industrial Management, Business Administration and Statistics at ETSII-UPM. ORCID Id.: 0000-0002-1663-3924

Rafael Miñano is a Ph.D. candidate involved in the Industrial Organization program of the Universidad Politécnica de Madrid (UPM). He is Associate Professor in the Department of Applied Mathematics for Information and Communication Technologies at the UPM.

Dr. Ana Moreno Romero is Associate Professor in the Department of Industrial Management, Business Administration and Statistics at ETSII-UPM. He is currently Deputy Vice-Dean for Social Responsibility.

Dr. Julio Lumbreras is Associate Professor of Environmental Engineering in the Department of Chemical Engineering and Environment at ETSII-UPM, and UPM Director for North America Visiting Scholar at the Harvard Kennedy School

Dr. Ruth Carrasco-Gallego is Associate Professor of Sustainable Supply Chain Management in the Department of Industrial Management, Business Administration and Statistics at UPM.

Dr. Rafael Borge is Associate Professor of environmental engineering in the Department of Chemical Engineering and Environment at ETSII-UPM.
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Corresponding author

Ángel Uruburu
ETS Ingenieros Industriales. UPM.
C/ José Gutiérrez Abascal, 2
28006 Madrid. Spain.
+34 913363146
angel.uruburu@upm.es

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PRODUCT, PROCESS, & SYSTEM BUILDING SKILLS EDUCATION BY CONSTRUCTING A CITIZEN SUPPORT SYSTEM

Mikiko Sode Tanaka, Takao Ito*

International College of Technology
*Kanazawa Institute of Technology

ABSTRACT

The difficulty of Product, Process, & System Building Skills education in regular lessons is that all techniques for developing products and systems must be taught in a limited time. In addition, it is impossible to teach students the requirements of analysis, architectural design, etc., in the limited time, as these cannot be learned without actually experiencing them. This paper introduces the educational method of product, process, and system-building skills involving collaboration with industry and community. The method is based on Project-Based Learning and is applied to students at the Kanazawa Institute of Technology and Kanazawa Technical College. Education was carried out under a curriculum involving a project for system construction supported as a Ministry of Internal Affairs and Communications IoT Service Creation Support Project. This paper explains in detail the practical project that was carried out in Nonoichi City. This was an educational project in which the students themselves thought about a given problem and methods of problem-solving by collaborating with companies and the city. In an effort to solve the given problem, we developed an information terminal bus stop and submitted proposals to Nonoichi City. Through active engagement with the project, students learned how to listen to individual requests, analyze the requests, and create the system. In addition, they also learned how to conduct the operational test, solve extraction problems, and improve the system. The project allowed students to receive hands-on education, and at the same time had favorable effects on the community. In fact, when using the prototype system for the citizens and conducting a questionnaire survey, we received numerous comments on its effectiveness in improving citizens' lives. Also, we confirmed students' growth from the student questionnaire survey.

KEYWORDS

Software engineering: Extracurricular activities: Regional collaboration: Project-Based learning:
STANDARD 5: Design-Implement Experiences:
STANDARD 7: Integrated Learning Experiences:

INTRODUCTION

An engineering education program that emphasizes the balance between knowledge and practice advocated in the CDIO syllabus is important in university education. We examined the program for education in “Conceiving, designing, implementing, and operating systems in the enterprise, societal, and environmental context” described in the CDIO syllabus（Edward F. Crawley, 2002, Edward F. Crawley, 2011） carried out at the same time as entrepreneurship education (QAA, 2012). In this paper, we will explain the conception, design, and implementation of the educational method and its effectiveness in citizen support system building.

The difficulty of Product, Process, & System Building Skills education in regular lessons is that all the techniques for developing products and systems must be taught in a limited time. In addition, it is impossible to teach students the requirements of analysis, architectural design, etc., in a limited time because these cannot be learned without actually experiencing them.

This paper introduces the educational method of product, process, and system-building skills involving collaboration with industry and the community. The method is based on Project-Based Learning (PBL)(Mikiko Sode Tanaka, 2017). It is applied to students at the Kanazawa Institute of Technology and Kanazawa Technical College. The educational effects of the method are explained.

The project was supported as a Ministry of Internal Affairs and Communications IoT Service Creation Support Project (Ministry of Public Management, 2017). The purpose of the IoT Service Creation Support Project is to identify specific problems that should be overcome when creating and deploying IoT services through demonstration projects, to build a reference model that will help solve the issues, and to promote data utilization. In addition, it is to play the leading role in the development and maintenance of the necessary rules for the IoT service. The group of Nonoichi City, NEC Solutions Innovator Co., Ltd., Yoshida Advertising Co., Ltd., Kanazawa Institute of Technology, and Kanazawa Technical College was selected for this project.

This paper explains in detail the practical project that was carried out in Nonoichi City. The city, located in Ishikawa Prefecture in Japan, requested the development of an ICT system for citizen support. We carried out an educational project in which the students themselves thought about the given problem and methods of problem-solving by collaborating with companies and the city. In the effort to solve the given problem, we developed an information terminal bus stop and submitted proposals to Nonoichi City. The developed system comprised five sub-systems: a Timetable and Transfer Guidance System, Children’s and Elderly Observation System, Disaster Countermeasure System, Advertisement System, and City Public Relations System. This system features image recognition software and provides service matching for each individual.

From active engagement with the project, students learned how to listen to individual requests, analyze the requests, and create the system. In addition, they also learned how to conduct the operational tests, solve extraction problems, and improve the system. The project allowed students to receive hands-on education, and at the same time had favorable effects on the community. In fact, when citizens used the prototype system and completed a questionnaire survey, we received numerous comments on its effectiveness in improving citizen life.

This paper will be organized as follows: First we present the intended character of the Product, Process, & System Building Skills education with Nonoichi City and the companies. Second, the educational method based on PBL is discussed. Third, we describe a detailed practical example of the bus stop project, which was the system development project for citizen support chosen. Finally, we integrate the findings and provide directions for the future of such Product, Process, & System Building Skills education.

FEATURES OF PRODUCT, PROCESS, & SYSTEM BUILDING SKILLS EDUCATION

Purpose of the Project Activity

Society is constantly changing. In the information processing field, this is quite noticeable. We believe that the ability to respond flexibly to this change, the creation of new value, and the ability to lead society in a better direction are important. We believe that we should actively tackle social issues and focus on developing human resources able to improve society. Based on this philosophy, we are working on the development of regional innovation systems through community collaboration as extracurricular activities.

We posited that the three requirements for becoming a global leader are as follows and aimed at students acquiring these abilities.

A) Recognition / comprehension to cope with social change
B) Power to change one's own interests and abilities into actual behavior
C) Spirit and power to fully utilize one's own resources and solve social problems

We targeted Nonoichi City, in which the university is located, and tackled the matter of the improvement of civic life, because students who are citizens think that it is meaningful to solve their own civic problems themselves and to enrich the lives of other citizens. Another purpose of the project was to develop their software development capability by developing an ICT system for citizen support. By educating them in the system design method while actually creating the system, we aimed to improve students' skills as information processing engineers.

Flow of the Project Activity

We believe that by designing and implementing with an entrepreneurial spirit rather than designing and implementing the system as set out beforehand, we will acquire more useful skills in society. Therefore, our curriculum combines entrepreneurship education, such as the construction of a business model, and CDIO education: "Conceive, Design, Implement, and Operate." The flow of system development education in the bus stop project is as follows. We built the flow based on the system development flow carried out in this enterprise (Hirofumi Naito, 2006).

1) Planning: "Assembling the concept"
2) Planning: "Building a business model"
3) Proposal: "Create a business plan"
4) System design and construction

5) Introduction / deployment
6) Operation and maintenance

This is a mechanism to learn this process in a few years. For that reason, students cannot learn all of the flow in four years, and depending on the year of admission cannot learn it in order starting from Phase 1. The size of the project group is about five people in a general enterprise, and it is a project to be carried out over a period of half a year to a year. As the students are changing each year, it is structured to take place over about six years while various learning occurs in the activities carried out for three or four hours once a week. Currently in Phases 3 and 4, we are considering of the process of commercialization. In this paper, we describe the system development method education in Phase 4.

For software development, various indirect management tasks are required to create not only the work directly related to the development of software, such as request analysis, design, implementation, and testing, but other work as planned. As the scale increases, the importance and weight of such management work will also increase. In software engineering, a project is defined as periodic work carried out to create unique products, services, and products (Tomoji Kishi & Natuko Noda, 2006). The goal is to reach the deadline under the cost and resource constraints that the project is to achieve. We believe that developing the ability to develop software in limited time, cost, and resources is an important factor in education in the field, and in this activity we carried out activities involved in the project.

The major difference from regular lesson classes is that we must develop the practice of keeping pace with the citizens and city officials who are customers and with the cooperating companies. We have to manage the requirements, cost, and time constraints of customers at the company level. In order to make the project successful, we must plan and implement it appropriately. For example, one must plan what to do day by day to achieve the final goal. In order to do so within the prescribed time period and cost, one must plan and implement properly by how much time and cost each factor should be multiplied. We must avoid time and cost overruns and ensure the project reaches its goal. In addition, as students execute the project, teachers must consider student human factors and develop members' abilities accordingly.

EDUCATIONAL METHOD BASED ON PBL

With the aim of improving citizen support, we investigated one problem of Nonoichi City. In Nonoichi City, a comprehensive planning document has been released which introduced the city policy and compiled the opinion of the citizens as to in which direction the city should go. We decided to focus on what we could do to enrich the lives of citizens within the comprehensive plan. The issues that we decided to solve are:

1) Improvement of transportation convenience
2) Child observation
3) Elder observation
4) Disaster countermeasures
5) Advertisement for city publicity and city revitalization.

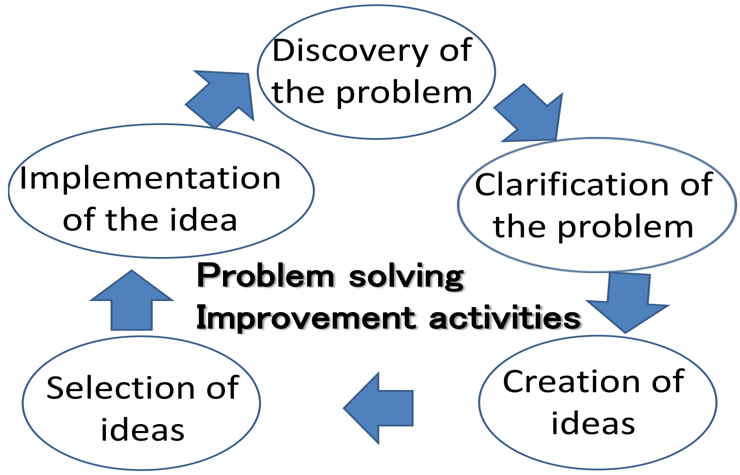

Figure 1. Flow of problem solving and improvement activities

Figure 2. Students explaining ideas to the Nonoichi City official

For the task selection, the flow of problem solving and improvement activities shown in Figure 1 was used. First of all, the students discovered and clarified the problem, create ideas, selected and realized the idea, and discussed it with a Nonoichi City official (Figure 2). This was repeated a number of times to bring the ideas of the Nonoichi City official and students' ideas into conformity and set the final task of the project.

DETAILED PRACTICAL EXAMPLE OF THE BUS STOP PROJECT

Our project was adopted by the Ministry of Internal Affairs' "IoT Service Creation Support Project", and it was decided to carry out a demonstration experiment of a smart bus stop in Nonoichi City. In order to make the project a success, we had to develop a system in collaboration with parties actually able to meet only a few times. Students must have the ability to develop programs without bugs according to a schedule set in collaboration with the company. Students were required to acquire skills that they had never had before.

Although the network of the system was built only on the Internet, we had to rebuild the main network using LoRa, which is the standard for IoT. As a result, hardware (printed circuit board design, development), embedded software, a transmission test, and network construction were also added as project tasks. Regarding human recognition, we worked on the assumption that a person was standing before, but had to be recognized walking. Sending an image of a person by using LoRa takes about 24 hours for one image. Since this is not realistic, we had to examine the image compression method. The project had a number of technical problems. Figure 3 shows an overview of the developed system.

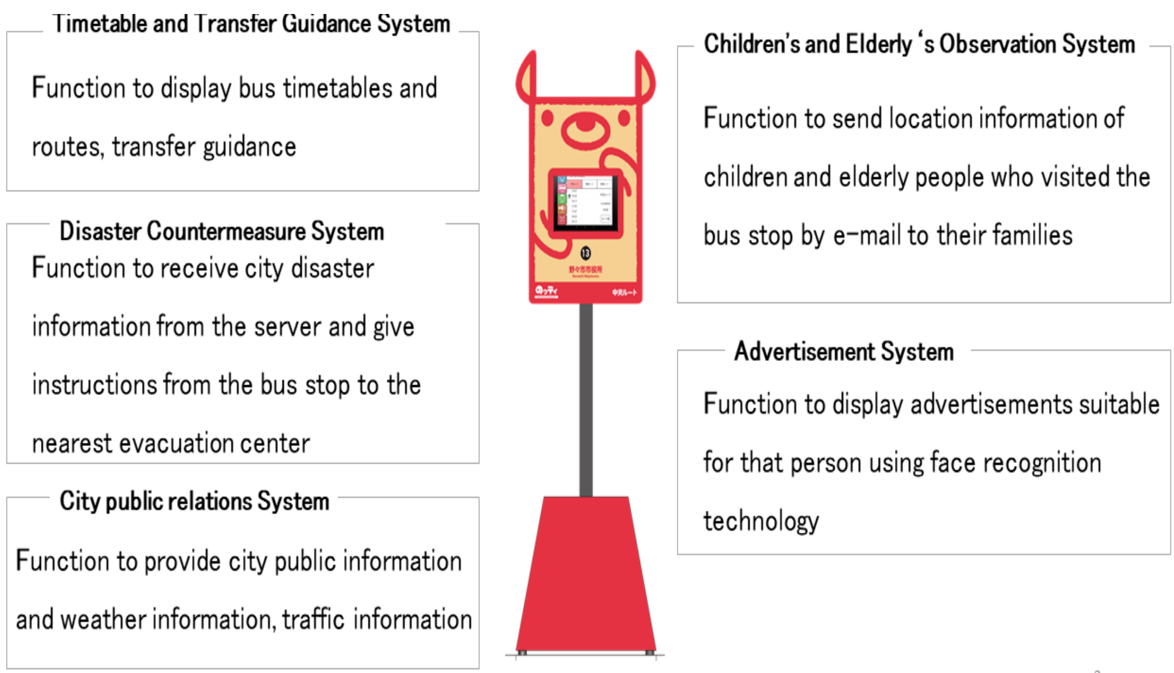

Figure 3. Citizen support system for Nonoichi City

Figure 4. Demonstration experiment carried out in Nonoichi City

At the time they participated in the project, students who had not even written a program carried out research and development and conducted demonstration experiments. It became a harsh, onerous project that had to be completed in about six months. Students sometimes worked overnight, as did the teachers. In the end all this work paid off and we were able to carry out demonstration experiments with no accident (see Figure 4). In addition, students were able to publish papers through IEEE, etc. (Ryoma Aburano et al., 2016, Taku Kuribayashi et al., 2017, Hiroki Nishino et al., 2017). Presentations in English seemed to put the presenters into a panic, but we think that this was also a good learning opportunity.

Although the system operated without bugs in the demonstration experiment, several problems have been revealed in processing speed and usability. We collaborated with the company, created a major system, carried out demonstration experiments, and completed the project successfully, but from the system point of view there are still problems, and we learned there are high technical walls. “If you can speed up the system, you can get it used not only in Nonoichi City but also in the downtown area,” was gently pointed out. We do not know how far students understand the meaning of the word, but we think that they learned that there is much work to complete a system so it operates without bugs.

EDUCATIONAL EFFECTS OF THE BUS STOP PROJECT

Citizen Questionnaire Survey Results

We actually set up the information terminal bus stop that we created at the bus waiting area of the Nonoichi City Hall and conducted a survey of citizens (Roma Aburano et al., 2016). Figure 5 shows the questionnaire survey image. To the question, “Is it necessary to convert the bus stop to an information terminal?” the answer that it was necessary was given by 84% of the respondents (Figure 6). To the question, “How do you think the information terminal bus stop will be of help?" 50% answered the improvement of the convenience of the transportation system of the city, 26% the safety of the city or contributions to safety, and 24% greater effectiveness in revitalizing the area by disseminating city information (Figure 7). From the results of the questionnaire survey, we confirmed the effectiveness of the system that the students planned and developed.

Figure 5. Questionnaire survey about the information terminal bus stop

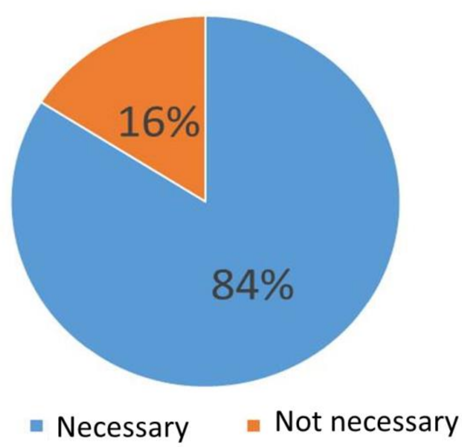

Figure 6. Questionnaire survey on the effectiveness of the information terminal bus stop

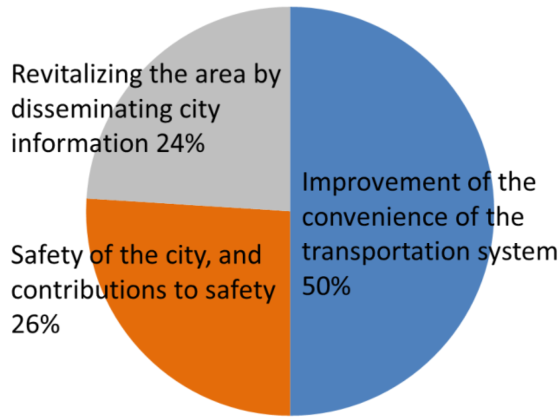

Figure 7. Questionnaire survey on the effectiveness of the information terminal bus stop

Student Questionnaire Survey Results

We conducted a questionnaire survey on participants' abilities to acquire the skills required for system design by participating in the project. In response to the question as to whether their programming ability improved, 89% of the students responded that they improved. Also, 38% of the students said that their progress management abilities used in the project improved. Moreover, 50% of the students listened to the client's request and answered that the ability to build a better trust relationship improved, while 68% of the students responded that the ability to work smoothly with project members improved. We received good feedback from students that they were able to learn practical contents and were able to participate well in the project. From the results of the questionnaire survey, we confirmed the effectiveness of our education system.

FUTURE DIRECTIONS OF THIS PROJECT

We gave an explanation about the extracurricular lesson learning how to build a system in the project. This activity conforms to the CDIO syllabus, which consists of four parts (Edward F. & Crawley, 2002, Crawley & Edward F., 2011) as follows.

1. Disciplinary knowledge and reasoning
2. Personal and professional skills and attributes
3. Interpersonal skills: Teamwork and communication
4. Conceiving, designing, implementing, and operating systems in the enterprise, societal, and environmental contexts

In order to make it a stronger education system in the future, we think that it is necessary to add system maintenance education. It is important not only that the software system can be constructed, but also that it can operate without money and adds systems according to the users' requests. Programming techniques that are easy to maintain and facilitate the addition of new functions are important and cannot be learned without experience. In the future we would like to devote efforts to creating a curriculum for this part.

CONCLUSION

The difficulty of Product, Process & System Building Skills education in regular lessons is that all the techniques for developing products and systems must be taught in a limited time. This paper introduced the educational method of product, process, and system building skills in collaboration with industry and community. Education was carried out using the curriculum of a system construction project supported as a Ministry of Internal Affairs and Communications IoT Service Creation Support Project. We carried out an educational project in which the students themselves thought about a given problem and methods of problem-solving by collaborating with companies and the city. In an effort to solve the given problem, students developed an information terminal bus stop and submitted proposals to Nonoichi City. From active engagement with the project, students learned how to listen to individual requests, analyze the requests, and create the system. In addition, they also learned how to conduct the operational tests, solve extraction problems, and improve the system. The project allowed students to receive hands-on education, and at the same time had favorable effects on the community. In fact, when and conducting a questionnaire survey of citizens using the prototype system, we received numerous comments on its effectiveness in improving citizens' lives. Also, we confirmed students' skills growth with a questionnaire survey for students.

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BIOGRAPHICAL INFORMATION

Mikiko Sode Tanaka is an Associate Professor at International College of technology.

Takao Ito is a Professor at Kanazawa Institute of Technology.

Corresponding author

Dr. Mikiko Sode Tanaka
International College of Technology
2-270 Hisayasu Kanazawa Ishikawa 921-8601, Japan
81-076-248-1080
sode@neptune.kanazawa-it.ac.jp

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INTERACTIVE TEACHING IN INTERPERSONAL SKILLS AS INNOVATION IN ENGINEERING EDUCATION

Jørgen Erik Christensen[1], Markku Karhu[2], Cecillia Christensen, Jonita Martelius[2]

1) Department of Civil Engineering (Byg), Technical University of Denmark
2) Helsinki Metropolia University of Applied Sciences

ABSTRACT

Nowadays the typical engineer has working conditions different from before. They require many competences other than just the hard-core technical ones: personal and professional skills, multidisciplinary teamwork, communication, communication in foreign languages and leadership skills; thus, the personal competences are becoming more important. It is vital that the modern education for engineering students meets the demands of the business life of today, where the engineer has to solve both technical and interpersonal problems. For this reason, it is important to implement practises of interpersonal skills in the engineering education. International communication is one of the issues becoming more important in the globalised world of today. The CDIO Syllabus narrates the needed skills and one way of improving the quality and ideas in the CDIO implementation is through international co-operation. In this case the co-operation was begun through the invitation of Associate Professor Christensen to give an International Communication Course, in February 2010, at **Helsinki Metropolia University of Applied Sciences**. This invitation has been repeated twice a year since then. The International Communication Course is an innovation in engineering education based on the development of teaching methods for learning interpersonal skills in interactive classes –enabling the students to gather their own experiences through active involvement in exercises in groups of two to six persons. In order to improve the course a couple of initiatives were implemented. One is a course booklet, which contains all issues to be approached during the course. The students read the booklet beforehand and thus the course just consists of interactive exercises with interventions of explaining, sharing comments and discussion. Sharing comments and discussions are very important as they both tell the students that others have similar problems and issues as they do; but they also show the differences between young people from different cultures. In a class there are usually participants from 15 different countries and students from 55 countries have taken the course so far. Another initiative is that the students have to do three assignments. One reason for this is to see if they are able to apply what they have learned; but also to avoid students that will not deliver the efforts required. This has elevated the level of learning significantly. Based on students' assignments written during the courses and the course booklet, the content of the course was crystallized, a book was written and published in 2017 by Metropolia. This paper discusses our experiences of the international CDIO co-operation, implementing an International Communication Course at Metropolia.

KEYWORDS

Communication, interactive teaching, integration of international students, Interpersonal skills, teamwork. Standards: 2, 8, 11

INTRODUCTION

The importance of communication is increasingly recognized and acknowledged in engineering education. Successful performance of the engineering profession requires engineers to understand and explore customer needs, negotiate contracts, and collaborate in working teams. Communication in different styles is highly needed in all sectors of engineering fields. Of course, similar requirements concern professionals of other fields, too. Due to the increasingly globalized market, professionals who possess the ability to effectively communicate between cultures are in high demand. International communication studies are often ignored in regular engineering curricula, although any form of communication plays an important role in an engineer's everyday work life. The core of communication is to understand what the information messages are and how they are sent, received and processed. It is essential to learn to pay attention to the content (what) but also to the relational message (how).

Design Build Course – Danish Technical University (DTU), Denmark

At DTU, Department of Civil Engineering the first CDIO course was developed in the autumn 2008 for the first semester students (Krogsbøll et al., 2010), (Krogsbøll et al. (2011). The CDIO course was introduced as a *Design Build course*, where the students had to build a model house in the scale of 1:20 as a model of a realistic house (Christensen et al., 2009), (Rode et al., 2011). Each group of students had to go through all the CDIO processes, starting with the conceive phase with a lot of ideas, designing the house, constructing the house in the implement stage, and finally operating the house outside in the natural environment by measuring the heat loss for one month and comparing these results of heat loss, see Figure 1 – left.

When the students work together as a group in the CDIO process, it is extremely important that they can communicate in a satisfactory and positive way. It does not help them to be a well-educated and skilled engineer if they are unable to communicate with colleagues, partners, customers, etc., (cf. Figure 1 – right). In the development process of the *Design Build course,* it became quite clear that the students needed to improve their communication skills in order to get the full benefit of the CDIO process.

The experience from the CDIO *Design Build course* has inspired us to innovate a course in communication for engineering students. This paper explains the results from this process.

Figure 1. Left: The final model of a house. Right: The students need to communicate in the CDIO process during the course.

BACKGROUND, INTERNATIONAL COMMUNICATION COURSE – ICC

Traditionally the structure of teaching lessons is a 45-minute monologue by a teacher. However, the engineering students of today demand teaching which is both interesting and engaging. The teacher needs to present the subject in a variety of ways with different kinds of teaching activities and should have a wide repertoire of teaching methods and study forms for different occasions and to supplement with a variety of student activities (Biggs, 1999), (Biggs et al., 2007), (Christensen et al., 2007), (Grasha, 1996).

In many technical universities, there is a lack of focus on teaching interpersonal skills such as ethics, communication, co-operation, engagement, leadership and teamwork. It is imperative that space is allowed in the curriculum for courses in the interaction skills. Training the communication skills in engineering specific programmes is a relatively new concept, but it is highlighted and applied in the CDIO approach. The CDIO approach is a model made to develop and ensure comprehensive coverage of the engineering education. The letters indicate the stages or the lifecycle of a process, product or system. Modern engineers are involved in all stages, which are **Conceive**, **Design**, **Implement** and **Operate**. According to Crawley et al. (2007), the *Conceive* stage means to explore customer needs and to develop plans. The *Design* stage focuses on creating the design that describes what product, process, or system will be implemented. The *Implement* stage is to transform the design into the product and the *Operate* stage concerns usage of the product.

According to Crawley et al. (2011), the CDIO Syllabus v2.0 consists of four parts. (cf. Figure 2). They are 1) Technical Knowledge and Reasoning, 2) Personal and Professional Skills, 3) Interpersonal Skills, 4) CDIO.

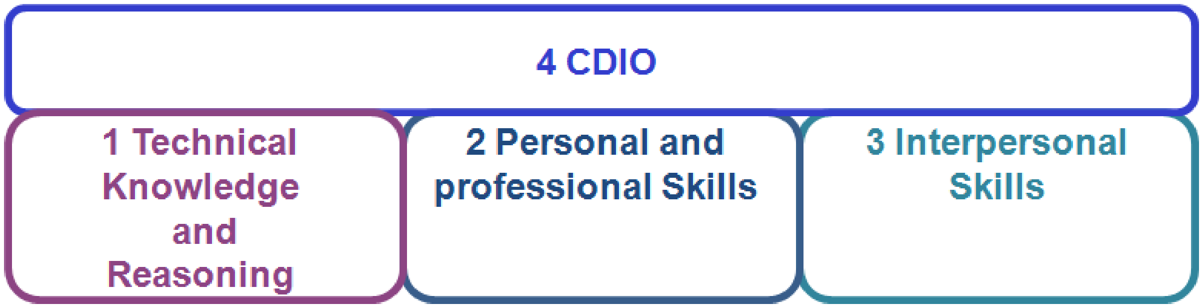

Figure 2. The CDIO Syllabus. Adapted from Crawley et al. (2011)

Figure 3 shows that the working conditions of the typical engineer nowadays include many other competencies than just the hard-core technical skills – sections 2.1, 2.2 and 2.3. They also include personal and professional skills, teamwork, communication and communication in foreign languages – sections 2.4, 3.1, 3.2 and 3.3. For this reason, it is essential that modern education for engineering students meets the demands of today's business life, where the engineer has to solve both technical and interpersonal problems, thus creating good results from an all-round perspective. It is also important to pursue interpersonal skills in engineering education. There is, however, a tendency in engineering educational programmes to give the implementation of this pursuit lower priority. Accordingly, this field therefore really needs innovation, but perhaps something is changing. When looking at the CDIO papers from former years more and more include the words interpersonal skills and especially 2017 had quite a number of papers related to the subject.

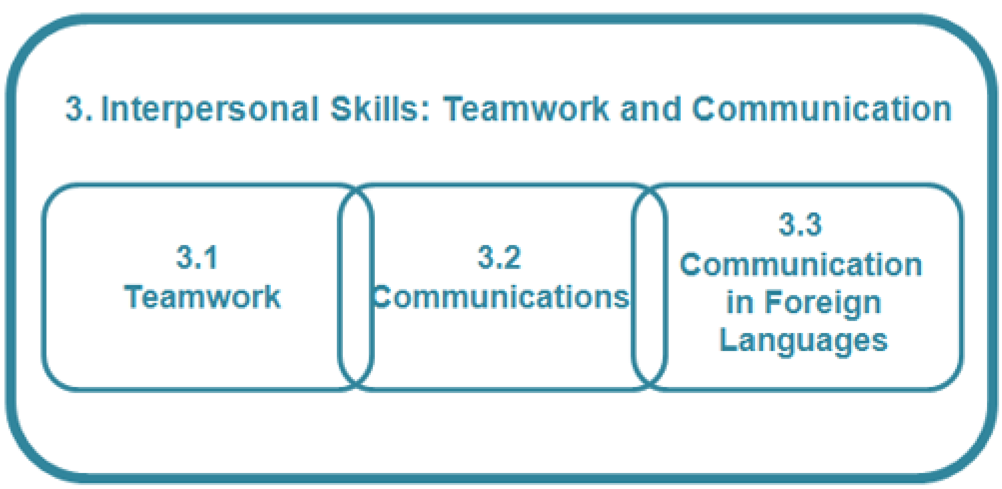

Figure 3. Adapted from Crawley et al. (2011): The second level of the Syllabus

DESCRIPTION OF INTERNATIONAL COMMUNICATION COURSES – ICC

As a teacher at DTU Byg and Metropolia, it is desirable to find an optimal teaching method that gives students the best introduction to and understanding of the engineer's world. According to Meyer (2006): "*There is no teaching in the world that is good in itself*". According to Kruse (2006) one may use different characteristics in order to try to define good teaching. However, educational research shows that it is an advantage to use a wide spectrum of different kinds of learning models so that the students can get a wide approach to the syllabus and what is needed to become an engineer. Connecting with the introduction of CDIO at DTU Byg the development of this course focused on working according to what is described as "Part 3 Interpersonal Skills", see Figure 2. Another reason is that the skill levels of the students in the 21st century varied; as a result, the ability of learning cannot be taken for granted in the same way as before (Jank et al., 2006). According to Jank, the consequence is that: *"Students are more demanding; their most frequent complaint is that teaching is boring. This problem can be resolved only with a renewal of the culture method"*. In this way, CDIO becomes a natural contribution to this renewal of the teaching method and is designed to help meeting the students' needs for meaningful and focused instruction, since they are constantly exposed to a very large flow of information.

Based on the **CDIO** as a model, the stages have been applied and implemented in the International Communication Course in order to better correspond to the needs of the students.

Conceive stage

Before the course the students read a book to make them aware of difficulties in communication by getting ideas, uncover problems and finding the overall perspectives. Through this process they begin to develop awareness about their communication skills, followed by writing a short assignment (*Assignment 1*) in which they analyse these skills, also the students can explore themselves and get awareness of their challenges as a future engineer. By doing this they will be able to conceive an understanding of the problems and work with their personal behaviour for communication.

Design stage

During the course the students do some exercises that focus on creating solutions to problems and they describe the process that is to be implemented. Based on these exercises they work on an individual basis to be able to design their further improvement for communication skills and how to develop these skills. As a part of this they participate in many practical exercises in groups or pairs. After each of these exercises they analyse and talk about their experiences, and possibilities for further improvement are discussed. This stage concerns the CDIO standards 2 and 8 (CDIO, 2018).

Implement stage

In the Implement stage the design is transformed into the process or the realization of the chosen tools/solutions. This means analysing by discussions what happened during the exercise. How they felt, how it worked. Many times, there are some intense debates; it is great for the students to learn that other young people regardless of their origin and upbringing share the same feelings and experiences they do. Also, the students like to listen to the other students telling and finding that something which is important in one country could be utterly useless in another and this creates situations that are great subjects for discussion in our class. This stage is where the students recognize that they may have some challenges that they will be able to work with during the exercises. They transform the design into the process i.e. the realization of the chosen solutions. At the end of the course they implement these skills in practice by taking part in a bigger long-lasting exercise, where most of the elements of the course are being applied. During the course the students write their

Assignment 2 in which they have the opportunity to reflect on their experiences. This stage concerns the CDIO standards 2, 8 and 11 (CDIO, 2018).

Operate stage

The Operate stage has focus on the actual use of the chosen tools/solutions. After the course the students will be able to operate their improved personal communication skills after returning to their class in their own university – they have their focus on the actual use of the things learned. Part of this will be that they write their *Assignment 3* in which they reflect on and analyse what they have learned and how they will be able to use it in their future life. This stage concerns the CDIO standards 2 and 11 (CDIO, 2018).

THE STUDENTS OF INTERNATIONAL COMMUNICATION COURSES – ICC

Finland was one of the few countries in the world where it was possible for students from any country to study in English and for free up to September 2017, when a tuition fee was set for students coming outside EU/ETA countries. In some other countries studies are also free of charge; however, the teaching language is not English. Therefore, we have had students in our course who have travelled straight from their own country to Finland from all the continents meaning that they may arrive without much knowledge of European conditions. Since Finland is so hospitable there are usually students from approximately 15 different countries attending our International Communication Course (ICC). All together, we have had students from 55 countries from all over the world. Because the students are from so many different countries they really do get the opportunity to explore international communication.

In order to make everybody feel fine we first do some ice braking exercises where the students just get the chance to find out where everybody is from and the chance to talk with each other. Later based on the material studied beforehand, we go through some theory and related exercises. Each day the students have to monitor and write what happened. Especially this *Assignment 2* is extremely useful to teachers because it helps to evaluate how much the students really got from the day and the specific exercise. We have applied the results of this evaluation to change our course in several ways. When we read the *Assignment 3* we can really check if the students understand what it is about and how to actually use the learned skills in everyday life. As described below, this assignment also tells whether the students have focused on the course. Comparing assignments 1, 2 and 3 it is possible to get a clear understanding of the students´ development as well as to control that an effort has been made.

INNOVATION IN THE INTERNATIONAL COMMUNICATION COURSE

Since August 2012, the students have had to write three assignments. The main reason for this is to see if they are able to apply what they have learned. During the Conceive stage before the course, the students read the material and write their *Assignment 1*. During the course itself, which covers the Design and Implement stages, the students write their *Assignment 2*. Six weeks after the course the Operate stage takes place where the students use what they have learned but now in their own environment and they finish the course by writing their *Assignment 3.* Since the International Communication Course is all based on doing practical exercises, it is essential that the students read the given material beforehand.

Writing assignments is a good way to assess whether the desired level has been achieved but it has also increased the level of learning dramatically.

The International Communication Course is structured in a way that helps preparing the students to take responsibility for their own learning while working actively. This is of great importance since development in society is accelerating, and students must cope with tasks that remain unknown while they are under education (Jank et al., 2006). Jank defines students as follows: *"Students are people who let teachers assist with learning. No outsider can make learning happen. One can only learn for oneself. Teachers are people who will assist students to learn".* When the course first started in February 2010 at Metropolia anyone enrolled were accepted to attend. However, this did not work out well after a couple of times when there were more than 60 students in the class. It is crucial that the students really attend all class sessions, because the most of them consist of exercises in pairs or small groups, see Figure 4. If a student does not work seriously with the given exercise, he/she destroys the effect and this will influence the partners' experience, too. *"Teamwork comprises forming, operating, growing and leading a team, as well as skills specific to technical and multidisciplinary teamwork."* (Crawley at al. 2011), so great emphasis is placed on the exercises being in teams. Some of the students attended to get easy ECTS credits. (ECTS European Credit Transfer System – used all over Europe, a method of measuring study programmes and transfer academic qualifications from one educational institution to another). They arrived late, they talked during the introduction of the subject, or they left for some hours in the middle of the course even though there is 100 % compulsory attendance. This made it necessary to check on those present several times during the day. In addition, it was somewhat difficult and took a day or two to find out who was there to learn and who was not. At one course, there was a bad incident where a Pakistani student hushed some Nepalese students, who bullied him later in the canteen.

Figure 4. Most of the course consists of exercises in pairs or in small groups.

In March 2011, we delivered the course in Alcala, Spain (Nyborg et al., 2011) for a group of students participating in an Erasmus Intensive course on *Developing Open Source System Expertise in Europe (DOSSEE)*. Since they had been forced to take, also some of our classes in communication many of them had a rather negative attitude. One of the students actually wrote in the evaluation:" *Not so much theoretical stuff, if you want to make a Social ICE-Breaking give us a bottle of alcohol and not some stupid exercises with a Danish couple."* One of the students in Spain was a Dane and since we are Danish, we had noticed him right away. He was studying Information Technology and could definitely not see the point in learning communication. Nevertheless, we did the exercises and somehow he suddenly got an epiphany, he got all excited and ended up taking pictures of all the material presented on the blackboard. In another class at Metropolia, we had a young man entering the room, taking the name badges (carefully placed in the alphabetic order) throwing them around, then taking his own and without a word going to sit down. These experiences among others have forced us to be more innovative about how we apply the CDIO model.

Innovation – Writing three assignments

As mentioned above, the students have to write three assignments. One reason for this is to see if they are able to apply what they have learned; but also to avoid students that just expect no efforts needed for participating in the course since the students make an assignment even before they join the course. We have found that 30-35 students at each course is the optimal number, so when we have many students wishing to join the course we can increase the level as to only get the students that will make an effort and who understand that being able to communicate is essential when you are an engineer.

Innovation – Timing of the course, integrated breaks

In the beginning, the course was scheduled for five days and only three hours a day, which was found not to be enough. For some years each day had a five-hour class which used to be from 1PM to 6PM. Finding that the students love the breaks when they get the chance to talk to someone they just found interesting during an exercise, the latest initiative was that our class in May 2017 was from 10AM to 4PM, so the students had a lunch break together.

The course is based on the students being very active and demands that they only take this course during that week. When the course was offered in the afternoon hours some students thought they were smart and took another course in the morning thus getting 6 ECTS points in just one week. When reading the Assignments 2 and 3 it was very easy to see that the students had not been fully concentrating on this course. They were not able to answer the questions (that is to understand the exercises), also the assignments were much shorter. When the students are doing what is required they each day spend about 45 minutes after class to write their Assignment 2 in order to be able to remember clearly what they experienced. Many times, the students only understand what really happened once they write about it, which is why so much effort is expected to be put into this assignment. It is the innovative process in the course – for the students it is a development that first they read about the theory, then they get their experiences during the exercises in class and then afterwards adapt them during the writing process – this makes the learning process deeper. From the students´ assignments, we can see that they currently get a far greater benefit. When it comes to Assignment 3, which is to be submitted six weeks after returning to their own university, it is also very easy to see that the students are not able to apply what they have learned if they did not focus during the course.

Innovation – Course material

When the course first started the students only needed to read approximately 15 pages of text. The required reading before attending the class increased as the course increased in lessons. Some parts of the booklet have now been written in a format of a book (Christensen et al., 2017) which is obtainable both as a printed book as well as in digital format free of charge. This latter being important since the students come from all over the world and need to be able to download the book and the pre-assignment before arriving in Finland.

Innovation – Presentation of theory and practice of exercises

In the beginning the course was based on a short verbal presentation without any digital presentations, followed by doing exercises and expecting that the students had read the booklet carefully. The students loved that they were doing exercises all the time; but they were not quite able to connect the exercises with the subjects. After having introduced Power Points as part of making a short presentation, the students now get a much better understanding of the subjects and have improved their ability to follow the structure of the course. Since the change the students are much more contended. We have now worked for some years to find an appropriate balance of theory and practice, and we now spend approximately 15 % of time on theory and 85 % on practice.

The different innovations have now made their impact on the International Communication Course and the students behave quite differently during the course compared to earlier.

CONCLUSION

In many technical universities there is a lack of focus on teaching interpersonal skills such as ethics, communication, co-operation, engagement, leadership and teamwork. It is important that space is allowed in the curriculum for courses in interpersonal skills. For some courses it should be a deliberate requirement, stated as a learning objective that the students will be evaluated on their interpersonal skills previously listed. Thus, they would feel urged to focus on their personal development knowing it is a part of the evaluation procedure.
Teaching so called softer skills can take place in strictly non-engineering courses on communication and interpersonal skills or in courses with technical substance. This paper presents the innovative process of a course development in order to use the CDIO concepts adapted to our International Communication Course. The innovation of the course has developed to be a strictly non-engineering course in communication. The duration of the course is a full week and it consists of various small exercises with personal involvement, whereby the participants can develop their interpersonal communication skills. Experience shows that the students appear to be very positive and delighted to attend the communication course, and they feel they can develop their interpersonal communication skills in interrelation with fellow students
The students having to write three assignments has made the most significant change of the course. It has made it possible to get in the class only the students that will make an effort and who understand that being able to communicate is essential for an engineer.

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BIOGRAPHICAL INFORMATION

Jørgen Erik Christensen is an Associate Professor at the Department of Civil Engineering, Technical University of Denmark (DTU). From 1997 to 2001 he studied gestalt therapy specialising in communication at the Norwegian Institute for Gestalt. In 2009 he studied "Pedagogical and Didactic Theory about University Education and Teaching" at the Danish Pedagogical University, Denmark. He has been involved in national and international research in the field of energy and environment and is a co-developer of an internationally used thermal analysis program known as tsbi3 (now BSim). Christensen has been a member of the CDIO implementation board of the Department of Civil Engineering at DTU.

Markku Karhu was the head of the degree programme in Information Technology at Helsinki Metropolia University of Applied Sciences for 20 years. His academic background is on Computer Science. His professional engineering experience is based on the research work of 20 years while applying software engineering methods to research projects at VTT Technical Research Centre of Finland. As an engineer educator, his interest in enhancing engineering education has taken him to participate in many European-wide engineering education projects as well as in the CDIO collaboration.

Cecillia Christensen received her degree as Interior Decorator in 1975. She has completed various courses in personal development and in 2002 was awarded her degree as NLP Master Practitioner.

Jonita Martelius is a senior lecturer on English and communication, French as a foreign language and cross-cultural communication at Metropolia University of Applied Sciences since 1999. She has also completed a degree in media education.

Corresponding author

Associate Professor Jørgen E. Christensen
Department of Civil Engineering (Byg),
Technical University of Denmark, Denmark
Phone (+45) 4525 1853 jec@byg.dtu.dk

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THE EDUCATIONAL INFLUENCES OF PROJECT DESIGN EDUCATION ON STUDENTS' LEARNING ABILITIES (The First Report)

Hung Nguyen-Xuan, Keiichi Sato

Project Education Center, Kanazawa Institute of Technology, Japan

Long Dam-Duy, Viet Nguyen-Xuan-Hoang

Vietnam - Japan Institute of Technology, HUTECH, Vietnam

ABSTRACT

Project Design (PD) education system, a reformed educational system from the 1995-developed Engineering Design system of Kanazawa Institute of Technology (KIT), has been playing a crucial role in the curriculum of KIT. The PD education system (*PD Introduction, PD I, PD II, PD Hands-on, and PD III)* that applies Project-based Learning (PBL), aims to nurture graduates to become successfully independent thinking engineers or business people. Within the collaboration framework established in 2014 by KIT and Ho Chi Minh City University of Technology (HUTECH) in Vietnam, the KIT's PD I and PD II courses have been adopted by HUTECH for its newly founded institution, namely Vietnam - Japan Institute of Technology (VJIT) in order to equip VJIT's graduates with global industry-ready abilities and skillsets that are aligned with CDIO Syllabus. VJIT has been implementing these KIT's PD courses for three years. This paper reports the results of a preliminary research survey conducted at KIT and VJIT on the educational influences of PD I and PD II courses on students' learning abilities and skills. The results of the survey show positive influences of these PD courses on students' learning abilities and skills in both institutions. The research also yields some recommendations for improving the practices of PD courses in both KIT and VJIT in the future.

KEYWORDS

Project Design, CDIO Syllabus, learning abilities, open-ended problem, solving process

INTRODUCTION

The Project Design (PD) education system, formerly named Engineering Design, serves as the main pillar in the curriculum of Kanazawa Institute of Technology (KIT) with the incorporation of Project-based Learning (PBL) approach. According to Shekar (2014), PBL can benefit the learning of students, including: a) enabling collaborative learning and deep learning by developing close teamwork and realization of personal development, b) helping reduce rote learning and plagiarism with frequent assessment, and (c) bringing about active learning. At KIT, PBL is one of the key factors in ensuring the quality of engineering education as required by engineering accreditation boards such as Accreditation Board for Engineering and Technology (ABET) and Japan Accreditation Board for Engineering Education (JABEE) (Ito et al., 2015).

In response to the increasing demand of industry and stakeholders in developing the desired attributes of engineers, many universities have been trying to address the necessity for reform in undergraduate engineering education. For this reason, the CDIO Initiative was developed to "educate students who are able to Conceive-Design-Implement-Operate complex, value- added engineering products, processes and systems in a modern, team-based environment" (Crawley et al., 2007, p. 1). Engineering education reform is "high on the agenda" worldwide and engineering skills have direct contribution to "the global economy, environment, security and health" (Campbell et al., 2009). In rethinking a new version for higher engineering education, Kamp (2016) notes that future engineers are not only "comprehensive problem solvers, but also problem definers, leading multidisciplinary teams in setting agendas, and fostering innovation" (p. 18). He further suggests three capabilities or roles that future engineers would need: a) "strong integrator capabilities to use and advance disciplinary expertise on its fringes, or fuse technological breakthroughs in one discipline with other disciplines"; b) capabilities of integrators to "synthesize, operate and manage across technical or organizational boundaries in a complex environment"; and c) "role of change agent, which means they must be prepared to provide the creativity, innovation, and leadership that is needed to guide research and industry to future success" (p. 21).

Beginning in 1995, KIT implemented several important educational reforms in engineering education. In 2006, KIT started to focus on development of students' comprehensive integrated abilities, including academic disciplinary knowledge and personal and interpersonal skills (Sato, 2012). In 2011, as a further step of its continuous education reform, KIT joined the CDIO Initiative with the purpose of further improving its engineering education quality through international cooperation, aligning with CDIO Standards (Sato, 2012) while at present, CDIO is being promoted for both KIT's curricular and extra-curricular activities. In 2012, Engineering Design of KIT was updated to the Project Design (PD) education system aligned with the CDIO Syllabus and Standards (Sato, 2012) to use for both engineering and non-engineering students. Now, the PD education system has been playing a crucial role in KIT's curriculum and has been taught to students across 14 departments of KIT.

In 2015, KIT joined a collaboration program with HUTECH. Under this program, HUTECH has adopted KIT's PD I and PD II courses for its newly founded institution, the Vietnam-Japan Institute of Technology (VJIT) in order to equip VJIT's graduates with global industry-ready abilities and skillsets that are aligned with CDIO Syllabus.

This paper aims to report the results of a preliminary survey of a joint international research project between KIT and VJIT, conducted at KIT and VJIT on the educational influences of PD I and PD II courses on students' learning abilities and skills. The paper also puts forward some recommendations for improving the Project Design education in the future in both KIT and VJIT.

CHARACTERISTICS OF KIT'S PROJECT DESIGN EDUCATION

After university, engineers face multiple open-ended problems, which are usually addressed by a team. For this reason, the PD education system at KIT has been developed to satisfy those requirements and also provide students opportunities to: experience the process of engineering design, combine ideas and knowledge in team activities and individually, and create new ideas and values. They develop their approach to problem-finding and solving step-by step, from simple to complex toward the systematic solutions. Figure 1 shows the framework of the KIT's comprehensive curriculum, in which the PD education system is the main pillar surrounded with knowledge-oriented education and hands-on education, with five following courses.

a) Project Design Introduction: Students experience experimental methods.
b) Project Design I (PD I): Students focus on creating ideas.
c) Project Design II (PD II): Students develop ideas created into shape.
d) Project Design Hands-on: Students verify ideas through experiments.
e) Project Design III (PD III): Students conduct a year-long project (a graduation thesis).

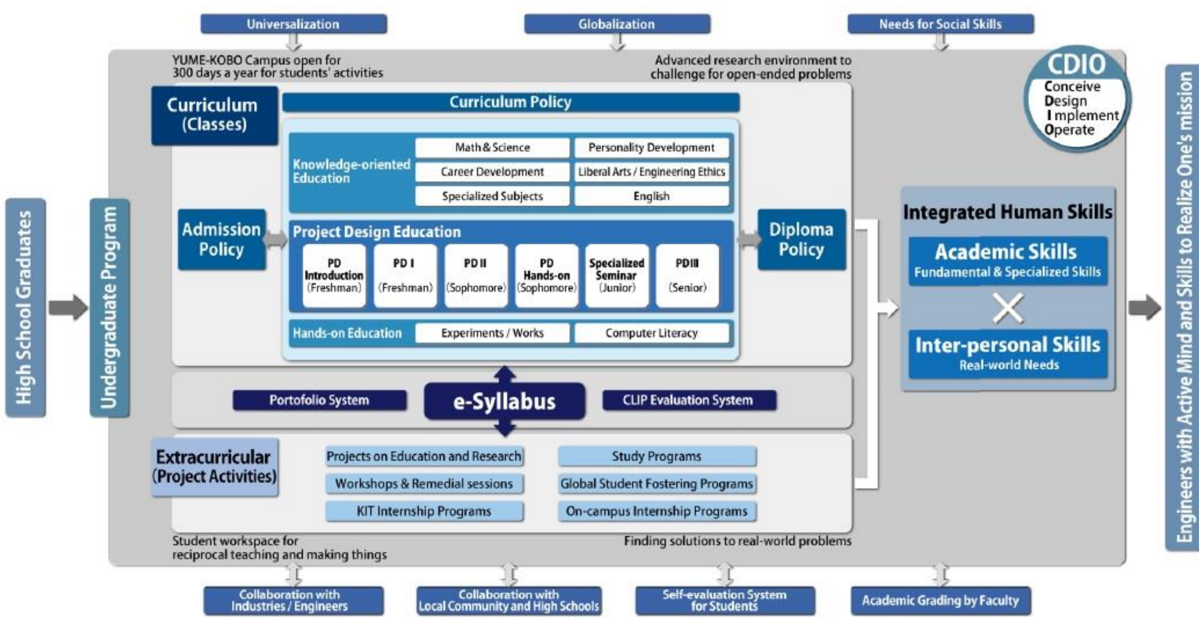

Figure 1. The current framework of KIT curriculum (Kanazawa Institute of Technology, 2017)

As the backbone of the KIT curriculum, PD education system has the following objectives (Kubo, Matsuishi, and Matsumoto, 2002; Saparon et al., 2017).

a) to train students to be independent thinking engineers through collaboration with others, learning the process and methods of problems identification and solving; solutions testing, verification and evaluation;
b) to allow students to think, act independently, and to implement active thinking; and
c) to allow students to present their creative results in a detailed and clear manner.

In short, KIT's PD education system provides students with problem solving skills, verification process skills, and innovation skills, which are needed to become successful engineers or businessmen in real life workplace. These are the key outcomes of the KIT's PD education (Ang et al., 2017; Saparon et al., 2017).

Project Design I & II Courses

In this paper, only the PD I and PD II courses are emphasized because they are directly related to our international research project. PD I, which is taken by freshmen, focuses on learning the process of acquiring problem solving skills by identifying a problem, collecting the information required, and reporting ideas. PD I has the following characteristics (Saparon et al., 2017).

(a) Integrate knowledge acquired from primary to secondary school, including university freshman course into solving a real-world problem. Scope and level of tasks are within the bounds of what students have previously learned.
(b) Discover a problem → Grasp current condition → Analyze the cause → Set the preconditions and desired conditions for the solution → Propose a solution for the problem.
(c) The main theme is presented as scope of the problem.
(d) Instructors are facilitators, supporting and encouraging students to be active participants.
(e) Problems are derived from students' own lives (or someone close to them).
(f) Promote awareness of the problems around them.
(g) Understand that there are many possible solutions to real-world problems and that it is necessary for those from different fields to work together.

PD II, which is offered for sophomores, also concentrates on the process of acquiring problem solving skills, but it addresses a different level of problems. This course requires students to tackle real-world problems (including those from local organizations or local governments) and to link with the PD Hands-on by making a plan to realize the concept selected.

Process of PD I & PD II Courses

In the PD course, students are taught many different approaches and students have to go through a process of solving that problem. Figure 2 describes the process of the PD I & PD II courses at KIT with five basic steps.

a) *Problem identification:* Students identify the problem around them.
b) *Problem clarification:* Students collect information and analyze the information related to the problem being addressed, and clarify the problem.
c) *Specifications establishment:* Students determine required specifications to be solved.
d) *Idea creation:* Students create as many ideas/ solutions as possible to solve the problem.
e) *Idea evaluation and selection:* Students evaluate and select the best idea/ solution among those developed.

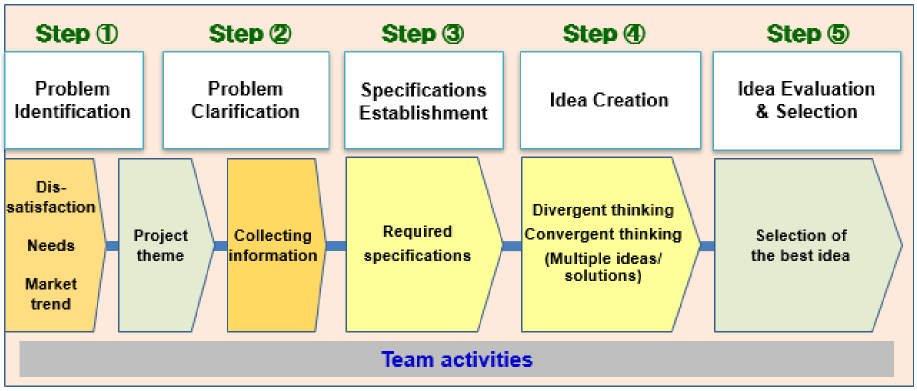

Figure 2. The process of PD I & PD II courses (Sentoku & Iwata, 2014)

During the course, students work on individual assignments and team assignments in equal amounts. Teamwork is one of the key characteristics of PD education. The students' performances are assessed based on their completion of both individual and team work (50% each), including worksheets, oral/ poster presentations, and final reports.

COLLABORATION PROGRAM BETWEEN KIT AND VJIT (HUTECH)

HUTECH has adopted the Project Design education system of KIT (currently PD I and PD II courses) for its newly founded institution, namely Vietnam-Japan Institute of Technology (VJIT) since 2015. Every year, VJIT sent their PD facilitators to attend PD professional training workshops at KIT to update their PD curriculum and facilitation skills. By adopting KIT's PD education, VJIT aims to equip VJIT's graduates with increasing globally desired skills and market needed abilities that are related to CDIO Syllabus and standards.

In implementation of these PD courses, there is a difference in the PD workflow between KIT and VJIT due to the different semester structure in the two institutions. For this reason, basic steps of the PD I and PD II courses, such as *problem identification, problem clarification, specification establishment, idea creation, idea evaluation and selection*, vary in weekly sessions in both KIT and VJIT (Figures 3.1 & 3.2).

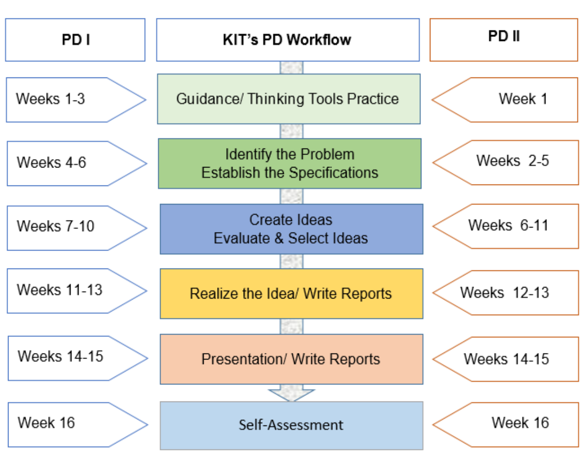

Figure 3.1 The PD I & PD II workflow in KIT

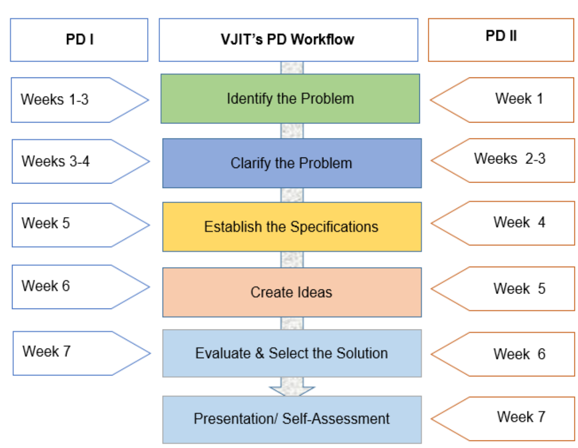

Figure 3.2 The PD I & PDII workflow in VJIT

A CASE REPORT OF THE PRELIMINARY SURVEY ON THE JOINT INTERNATIONAL RESEARCH PROJECT

This part of the paper reports the results of a preliminary research survey conducted in KIT (Japan) and VJIT (Vietnam) on the educational influences of PD I and PD II courses on students' learning abilities and skills, which are aligned with the CDIO Syllabus. The objectives of this international research project are to investigate the educational influences of these PD courses on the students' learning, especially on nurturing graduates to become successful engineers or business people in the future.

About the survey

The study used two types of survey questionnaire, one for PD instructors and the other for students. The Japanese versions were administered to the KIT's PD instructors and students, and the concurrent Vietnamese and English versions were used for VJIT's PD instructors and students. The content and number of questions are the same in two survey questionnaires.

Both types of survey questionnaires consist of two main parts. The first part asks about the general background of the respondents, such as gender, age, and specialization. The second part asks the respondents to rate: a) the influences of PD I and PD II on nurturing students' abilities (Items 1-16), b) the influences of PD I and PD II on students' learning of the specialized courses (Question 17), c) the satisfaction (Question 18) in learning PD courses (for students) and in teaching PD courses (for instructors) by developing the five-point Likert scale (1: *least influential and* 5: *most influential*). The following are 16 types of abilities investigated in the surveys of instructors and students, some of which are adapted from 'Desired Attributes of An Engineer' of the Boeing Company (Crawley et al., 2009).

An ability:
1) to tackle an open-ended problem in the real world
2) to identify customers' and societal needs
3) to discover and solve a problem
4) to make a presentation before an audience
5) to act and collaborate in a team (teamwork)
6) to lead a team (leadership)
7) to develop discussions in a team
8) to conduct good communication skills (written, oral, graphic, and listening)
9) to think critically, creatively, independently, and cooperatively
10) to understand the design process
11) to design things or systems useful for human society
12) to implement things or systems designed
13) to operate things or systems implemented
14) to practice high ethical standards
15) to adapt to changes (flexibility)
16) to learn for life (lifelong learning)

Survey Administration

In July 2017, two survey questionnaires were administered to VJIT, one for PD instructors and one for students, using Google Forms online. The online surveys were open for two weeks for accepting responses. In the end, ten complete responses from VJIT's PD instructors and 206 complete responses from VJIT's PD students of various specialized fields were received. At KIT, the questionnaires were printed and distributed to 97 PD II mechanical engineering students and 18 PD instructors.

RESULTS ANALYSIS AND DISCUSSION

Mapping of the abilities surveyed to the CDIO Syllabus

Since this research investigates the influences of the PD I & PD II courses on students' learning abilities (Items 1-16 in the questionnaire), a mapping has been constructed to show the correlation of the surveyed abilities to the first level of detailed content of the CDIO Syllabus (*ver. 2.0*). The purpose of this mapping is to confirm the correlation between the abilities/ skills learned from PD I & PD II courses and the contents of the CDIO Syllabus. Details can be seen from Table 1 below. Due to the limited extent of the current research, content 1 (*Disciplinary Knowledge and Reasoning*) of the CDIO Syllabus has weak correlations with the abilities surveyed, while contents 2 and 4 have more correlations.

Table 1. Mapping of the surveyed abilities to the CDIO Syllabus

CDIO Syllabus (Ver. 2.0)	Abilities surveyed															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1 Disciplinary Knowledge and Reasoning	△	△	△						△	△	△	△	△			
2 Personal and Professional Skills and Attributes	△	△	○	△	△	△	△	△	○	○	△	△	△	○	○	○
3 Interpersonal Skills: Teamwork and Communication	△	△	△	○	○	○	○	○								
4 Conceiving, Designing, Implementing & Operating Systems in the Enterprise, Societal & Environmental Context – the Innovation Process	○	○	○	△	△	△	△	△	△	○	○	○	○	△	△	△
△: Weak correlation ○: Strong correlation																

The survey results from the instructors

The results for instructors' ratings are presented in Figure 4 below.

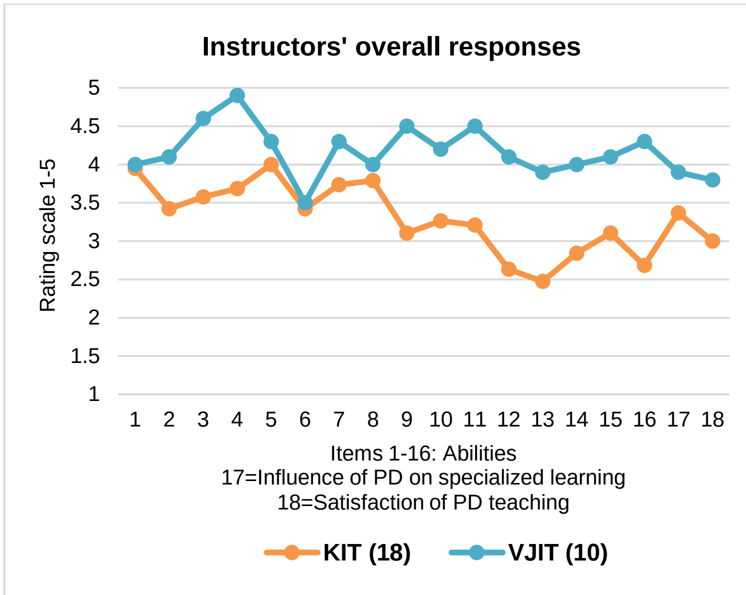

Figure 4. Instructors' rating

Figure 4 shows that the data distribution of the VJIT's instructors seems to be higher than that of the KIT's instructors on the rating scale (*1-5*) (VJIT's data *Mean*: *4.1*; KIT's data *Mean*: *3.2*). This may imply the influence of instructors' backgrounds and PD teaching experiences on the rating. The highest ratings of the items 1-16 by VJIT instructors are recorded on Items 4 (*4.9*), 3 (*4.6*), 9 and 11 (*4.5*), whereas KIT instructors rate Items 5 (*4.0*), 1 (*3.95*), and 8 (*3.78*) as the highest.

Of the Items 1-16 rated by VJIT instructors, some of the lowest ratings are found on Items 6 (*3.5*) and 13 (*3.9).* For KIT instructors, some of the lowest ratings fall on Items 13 (*2.47),* 12 (*2.63),* and 16 *(2.68)*. These low ratings indicate low influences of PD I and PD II courses on students' learning abilities, which can be predictable because these abilities can be obtained in advanced PD courses, such as PD Hands-on and PD III at KIT. We expect to investigate the influences of these abilities on students' learning of advanced PD courses in our future research.

The survey results from the students

There were 206 VJIT's PD II students and 97 KIT's PD II students participating in this preliminary research. Figure 5 shows the data of students' rating on 18 items, in which items 1-16 refer to learning abilities, item 17 asks about the influence of PD I and PD II on students' specialized learning, and item 18 asks students' satisfaction in learning PD I and PD II courses. For the purpose of better viewing, the original rating scale (1-5) has been zoomed in the scale of 3-4.

In Figure 5, the plotted data (Items 1-16) shows a relatively similar distribution of quantitative data collected from KIT's and VJIT's students (VJIT's data *Mean*: *3.99*; KIT's data *Mean*:

3.77). This quantitatively indicates a consistency of students' rating of PD abilities (KIT: Highest *3.92*, lowest *3.61*; VJIT: Highest *3.97*, lowest *3.59*). Of the Items 1-16, some highest ratings are found for VJIT on Items 5 (*3.97*), 14 (*3.92*), and 7 (*3.89*); for KIT on Items 5 (3.92), 8 (*3.86*), 3 (*3.82*), and 7 (*3.82*). The similar ratings of both KIT and VJIT students indicate PD I and PD II have influences on students' learning abilities of *acting and collaborating in a team* (Item 5) and *developing discussion in a team* (Item 7).

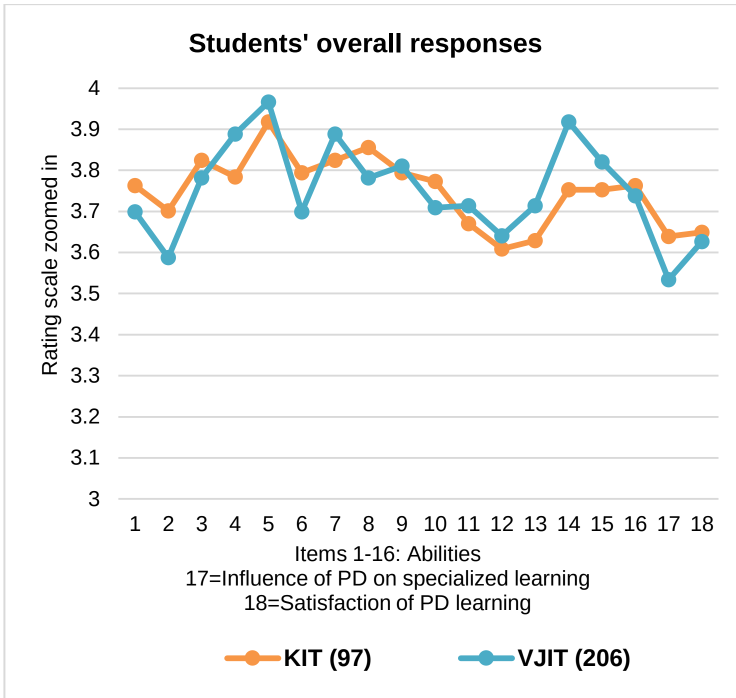

Figure 5. Students' rating

The lowest ratings are found for VJIT on Items 2 (*3.59*), 12 (*3.64*), and 1 *(3.7*); and for KIT on Items 12 (*3.60*), 13 (*3.62*), 11 (*3.67*), and 2 *(3.7*). The low ratings of Items 12 and 13 from both institutions' students are predictable as explained earlier in the instructors' data analysis. This result is consistent with the instructors' rating for these items. It is also necessary to note that compared to other items, Item 2 is rated as the lowest by VJIT students and also low by KIT students. This could be due to the inadequate provision of either course instruction or course activities that did not direct students' investigation into customers' and societal needs. This implies a need for improving this point in future PD courses. In terms of rating consistency between the instructors and students, the plotted data from Figures 4 and 5 shows a more consistent rating between instructors and students in KIT than VJIT.

Question 17 in Figure 5 shows ratings of the influence of PD I and PD II on students' learning of their specialized courses with a score of *3.64* for KIT and *3.53* for VJIT, which is quite consistent. These results confirm the consistency on the rating of this question from both institutions' instructors and students. Data of Question 18 shows both VJIT and KIT students' satisfaction in their learning of PD I and PD II courses (VJIT: *3.63*; KIT: *3.65*).

CONCLUSION

This preliminary survey as part of our three-year research project on Project Design education has attempted to investigate the influences of PD I and PD II courses on nurturing students' learning abilities. Sixteen abilities used in this research to survey the PD instructors and students from KIT and VJIT were correlated with the CDIO Syllabus contents. The findings revealed quite similar and consistent ratings from both instructors and students from KIT and VJIT. PD I and PD II courses had the most influence on students' learning abilities to *act and collaborate in a team (teamwork),* to *develop discussions in a team,* and to *conduct good communication skills (written, oral, graphic, and listening), and* the least influence on their abilities to *implement things or systems designed* and *operate things or systems implemented.* This result is predictable because the abilities with low influence from PD I and PD II courses are taught in advanced PD courses, such as PD Hands-on and PD III at KIT. Some important low ratings of other abilities are worth mentioning here, such as the abilities to *identify customers' and societal needs, to lead a team (leadership),* and *to learn for life (lifelong learning).* These low ratings have provided important insights for our future PD course design and classroom instruction in both institutions.

Since the current research is a preliminary one, its results, which are mainly quantitative, for external use may be limited. Our future research will continue to use the same questionnaire to students from KIT and VJIT to validate the results obtained from this research. Moreover, the findings reported here may not confirm all practical influences of PD education, but they have provided useful insights into PD education practices, PD curriculum reform, and PD instructors' training program in both KIT and VJIT.

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BIOGRAPHICAL INFORMATION

Hung Nguyen-Xuan is an Associate Professor at the Project Education Center, Kanazawa Institute of Technology (KIT), teaching Project Design Courses in English. He earned an M.A. degree in TESOL from Saint Michael's College (the U.S.) sponsored by the Fulbright Scholarship. His current research interests are curriculum design, teaching innovations, and Design Thinking.

Keiichi Sato is a Professor in the Mechanical Engineering Department and Director of the Project Education Center, Kanazawa Institute of Technology (KIT). His current research focuses on cavitation mechanism and waterjet technology in fluids engineering and on Project-Based Learning effects in engineering education.

Long Dam-Duy is Director of Project Design Education Center, Vietnam - Japan Institute of Technology (VJIT), Ho Chi Minh City University of Technology (HUTECH). He received his Ph.D. degree in Sociology from the University of Bourgogne Franche Comté (France). His academic interests include teaching and learning innovations to develop the tourism industry in Vietnam.

Viet Nguyen-Xuan-Hoang is Vice President of Ho Chi Minh City University of Technology (HUTECH), Director of Vietnam - Japan Institute of Technology (VJIT). He received his university diploma and Ph.D. degree in Electrical Engineering from Moscow State University of Transport Communication in 1992 and 1996 respectively. His research interests are power system protection and control, integrating the renewable energy into power systems, and smart grid implementation.

Corresponding author

Hung Nguyen-Xuan
Project Education Center
Kanazawa Institute of Technology (KIT)
7-1 Ohgigaoka, Nonoichi City
Ishikawa 921-8501, Japan
+81-76-248-8592
hnguyen2@neptune.kanazawa-it.ac.jp

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WATERFALL VS. AGILE PROJECT MANAGEMENT METHODS IN UNIVERSITY-INDUSTRY COLLABORATION PROJECTS

Marika Säisä, Katariina Tiura & Janne Roslöf

ICT-unit, Faculty of Engineering and Business
Turku University of Applied Sciences, Finland

ABSTRACT

In Engineering Education, students ought to gain competences relevant for the requirements of the working life. The CDIO Initiative has defined general goals to engineering education. That is, the aim is to educate students who are able to: 1) Master a deep working knowledge of technical fundamentals, 2) Lead in the creation and operation of new products and systems, and 3) Understand the importance and strategic impact of research and technological development on society (CDIO, 2010). Both disciplinary and interdisciplinary knowledge are needed in order to succeed as a future professional. Interdisciplinary knowledge such as project management skills are important in working life regardless to the competence area.

Agile project management has been a rising trend for several years especially in fields connected to Information and Communications Technology. The aim of the agile project management is to reduce failures by concentrating on delivering the most valued parts of the project and making dynamic changes if needed. Several companies use different agile project management ways to manage their projects. Scrum is one of most used ones. In order for a student to gain competences relevant for the requirements of the working life, both traditional and agile project management frameworks should be a part of their studies – in theory and in practice.

This case study compares waterfall and agile project management methods utilized in a set of university-industry collaboration projects. The study focuses on “theFIRMA” that is a learning environment at Turku University of Applied Sciences, Finland. The student-driven project office theFIRMA operates like a small company providing development projects to both university internal and external customers. TheFIRMA uses Scrum as an agile project management method. Typical customer projects are related to web development, graphical design, end-user trainings, user-testing, application implementations and Lego camps. In addition, theFIRMA participates in several externally funded R&D projects.

KEYWORDS

Waterfall, Scrum, project management, ICT, R&D learning environment,
CDIO Standards: 3, 6, 7 and 8

INTRODUCTION

Currently, there are two major project management domains: waterfall and agile. Agile project management has taken its place especially in ICT field projects where the continuous development takes place. Technical solutions and customer requirements change fast and thus, the need for agile methodology has been obvious. The aim of the agile project management is to reduce failures by concentrating on delivering the most valued parts of the project and making dynamic changes if needed. Various ICT companies use different agile project methodologies to manage their projects. Scrum is one of the most popular methodology applied in the companies (Scrum Alliance, 2015). Scrum methods are based on the Manifesto for agile software development: individuals and interactions over processes and tools, working software over comprehensive documentation, customer collaboration over contract negotiation and responding to a change, over following a plan (Manifesto for Agile Software Development).

Waterfall project management focus on careful and detailed planning so when the project is ongoing, it is easy to just follow the plan. Waterfall is a linear approach where the phases of the project follow each other. In some sense, conceive – design - implement – operate (CDIO) follows same kind of systematic and linear progress.

In Engineering Education, students ought to gain competences relevant for the requirements of the working life. The CDIO Initiative has defined general goals to engineering education. That is, the aim is to educate students who are able to: 1) Master a deep working knowledge of technical fundamentals, 2) Lead in the creation and operation of new products and systems, and 3) Understand the importance and strategic impact of research and technological development on society (CDIO, 2010). Both disciplinary and interdisciplinary knowledge are needed in order to succeed as a future professional. Interdisciplinary knowledge such as project management skills are important in working life regardless of the competence area.

Students in theFIRMA learning environment gain relevant interdisciplinary skills by participating in the projects in different roles. Multicultural and multidisciplinary teams do innovative work together to meet the goals of the projects and to create added value in customer pilots of theFIRMA. Every project has a student project manager who is responsible for scheduling and coordinating the activities. In agile projects, theFIRMA has chosen Scrum as a project management method and thus, the student project manager is usually a Scrum Master. Depending on the project, either teacher coaching the project team or the customer her/himself is the Product owner and responsible for communicating the needs of the customer for the project team. This approach not only deepens the disciplinary but also the interdisciplinary knowledge and skills of the students, since the project management skills are trained in authentic context.

In this paper, the focus is set to present a case study on comparing waterfall and agile project management methods in university-industry collaboration projects in theFIRMA. First, the activities and the roles of theFIRMA are described and experiences on R&D projects are presented. Thereafter, the customer project processes used in theFIRMA are introduced and compared. Finally, the past and current activities are discussed, and future development thoughts are presented.

THEFIRMA – ACTIVE LEARNING ENVIRONMENT

TheFIRMA learning environment is student-driven project office that serves mainly small and medium sized enterprises (SMEs) in Southwest Finland. Typical customer projects are related to web development, graphical design, end-user trainings, user-testing, application implementations and Lego camps. Students work in the project office learning by doing and work done in theFIRMA is integrated in the curriculum so that the students gain credits for the introductory course, work placement, thesis or separately agreed courses if the contents of the customer project is similar to contents and learning objectives this certain course (Säisä, Määttä & Roslöf, 2017). In addition, it is possible to complete tailored advanced professional studies in theFIRMA as well (Säisä et al. 2017). In 2016, over 150 students worked in theFIRMA learning environment and gained over 1500 ECTS credits (Määttä, Roslöf & Säisä, 2017).

Student-driven project office has an internal organization: the student CEO is responsible for general administration, staffing and selling activities. The student project managers coordinate the customer projects and lead the teams, and team members are focused on implementing the projects. Depending on the individual interests and competencies, the students can focus on different ICT engineering topics, such as website design, network administration, graphics design and software testing. TUAS staff mentor the students when needed, help with the negotiations with customers and make sure that the learning goals are met during the projects. (Roslöf, 2016)

There are three staff roles from TUAS: staff project manager, responsible teacher and technical consultant. A staff project manager has the overall responsibility of theFIRMA and its operations. S/he participates also in customer negotiations and helps defining feasible project goals, pricing levels and formal contracts. Responsible teacher takes care of the learning process and defines the learning objectives for the students and the projects. In addition, the responsible teacher agrees the amount of credits and assessments for the students. Technical consultants mentor the students in difficult engineering tasks that students are not able to solve by themselves. (Roslöf, 2016; Säisä, Määttä & Roslöf, 2017). TheFIRMA management team consists of staff project manager, responsible teacher, technical consultant, theFIRMA student CEO and the student project managers. Figure 1. depicts students working in groups in theFIRMA projects.

Figure 1. All of theFIRMA projects are done in groups where senior-level students mentor the junior level students.

TheFIRMA participates in several externally funded R&D projects, where the focus is, for example, on digitalization of SMEs and digitalization of circular economy. The “Hot Potato” project implements 50 customer pilots with Finnish SMEs and based on the experience gained in the pilots, creates guidelines for the companies interested in digitalization, gamification and knowledge management. Pilots are focused on rapid experimenting in companies that are eager to develop their performance further, increase productivity and enhance well-being at work. Pilots are done in co-operation with 50 Finnish SMEs, TUAS and University of Turku. The project is funded by partner universities, companies and European Social Fund. (Säisä et al., 2017). The main goal of the rapid experiments in ”Hot Potato” is to try something new with the customer company, and if the experiment seems fit well for its purposes, then it can be adopted into companies processes. On the other hand, if the experiment reveals that it does not fit the company’s business nor processes, it can be quickly abandoned and changed to a new rapid experiment. In some cases, instead on long-lasting planning phase, it is just good to try new process, new prototype or new service and see how it fits. The scrum methodology suits well with rapid experiment projects.

IMPLEMENTATION OF CDIO

The CDIO Initiative has defined 12 CDIO Standards (CDIO, 2010) to describe the features of CDIO programmes. TheFIRMA learning environment meets standard 3. “Integrated curriculum” by integrating regional customer cooperation as well as externally funded R&D project to curriculums of ICT engineering students and thus, enhances the learning experiences that lead to the acquisition of personal and interpersonal skills, and product, process, and system building skills. The standard 6, “Engineering workspaces”, accentuates the importance of physical learning environment. TheFIRMA office is located in the campus with dedicated facilities. The physical project office provides room for the teams work together in peace and also to meet the customers. In addition, joint facilities provide opportunities for networking and wider co-operation. The standard 7, “Integrated learning experience”, engrosses on acquisition of disciplinary knowledge simultaneously with personal and interpersonal skills. Authentic customer pilots produce fruitful platform for simultaneously learning of disciplinary knowledge. TheFIRMA actively encourages students to be self-driven, thriving to learn more and eager to solve troublesome assignments, which are also described in the CDIO standard 8 (Active learning).

THE CUSTOMER PROCESS IN THEFIRMA

Most of the customers of theFIRMA are small and medium sized companies located in Southwest Finland. Potential customers contact theFIRMA in various ways, such as via theFIRMA website or through TUAS RDI-service. The first meeting with the customer is about understanding the needs and the business processes of the customer as well as discussing the potential co-operation opportunities. Usually this meeting is between the customer, the staff project manager, the student CEO and/or student project managers of theFIRMA. If the potential customer is interested in co-operation, theFIRMA management team prepares a project offer for the customer. The offer includes description, schedule and the price of the project.

Once the customer agrees the project offer, project preparation is started. Preparation phase consists of finding a suitable project team of the students and mentor from the teachers, writing more detailed project plan and internal project kick-off meeting with the project team members. Project teams are formed in a way that senior-level students mentor the junior team members. The kick off phase includes going through the customer´s business processes, aim and scope of the project as well as learning goals of the team members. At the kick-off meeting the team and the mentor will decide whether the waterfall or scrum is being used during the project.

The implementation part starts with a customer meeting where all the team members finally meet the customer and are able to ask clarifying questions from the customer. Students tend to work more systematically and accurately when the teaching of different professional skills alongside disciplinary knowledge is integrated into the business context (Mejtoft, 2016, p. 689). Meeting with the customer face-to-face and understanding the business of the customer also increases the motivation and commitment of the students. Meetings with the customer, mentor and project team occur regularly throughout the project implementation.

In the end of a customer project, a closing meeting will occur, where all the team members, mentor and customer meet and go through the aim of the project, results and customer feedback. In order to make sure that the project really helps the customer in a long run, mentor can schedule another meeting after couple of months to make sure that the customer has conducted the new processes designed in a project. For example, in a website design project, customer is trained to update the contents of the new site by him/herself. In some cases, customer might need some extra training to adopt the new platform to daily/weekly business routines.

There are three different roles in the Scrum framework: the Product Owner, the Team and the Scrum Master. The product Owner is responsible for representing the requirements of everyone concerning the project as well as projects resulting system. In addition, the Product Owner makes sure that the prioritizing the items in Product Backlog. The self-managing and self-organizing Team is responsible for developing functionality. The Scrum Master is responsible for Scrum Process, for training the Scrum methodology for team members and for ensuring that everyone follows Scrum rules and practices. (Schwaber, 2004; Rubin 2013).

If the project has been decided to be implemented by using Scrum, the sprints are usually two weeks long. Depending on the project, the division of the Scrum roles can be done in two ways: 1. Customer works as a product owner, teacher/mentor works as a Scrum master and team members work as a development team. 2. Teacher works as a product owner, student project manager works as a Scrum master and the rest of the team members work as a development team.

AGILE OR WATERFALL?

The decision whether to use agile or waterfall as project management in a customer project depends on the aim, scope and schedule of the project. In addition, customer's commitment and schedule has to be taken into account since customer has to be highly involved with the project team if the project is run with Scrum. If the customer project is related to end-user training, such as MS Excel training or MS Outlook training, the aim and the scope of the project is rather straight forward. If the customer project is about designing new application, the aim and the scope might change during the project and very close customer cooperation is needed throughout the project.

Using waterfall as a project management methodology, project is planned and scheduled carefully beforehand. In a sense, project is easier to lead, when the waterfall methodology is used. Also, according the experiences in theFIRMA, students understand the whole project cycle better, when it is designed and implemented with waterfall. In addition, planning the resources is much easier. In a project office, where the main workforce is the students, the schedule of each student varies depending on their classes. On average, students work in theFIRMA 10-15 hours per week. This has to be taken into account, when the project is being scheduled. However, the down side of the waterfall projects is that quite often the schedule of the project changes, especially in longer projects. Team members get sick, some of team members get a new job and quit the project, or customer is so busy that s/he is not answering the emails. Table 1. demonstrates the pros and cons of scrum and waterfall project management methodologies.

If the scope and/or the final result of the project are not totally clear in the beginning, the scrum is being used as a project management methodology in theFIRMA. Scrum offers variety of tools to easily adopt the change during the project. In addition, less planning is done in the beginning, so team members do not use that much time in features that might not be part of the final solution. In theFIRMA the length of each sprint is for two weeks, so short-term goals are easy to adopt and schedule by students. However, the big picture of the whole project might be incoherent for the students, since the project is built of small pieces. In addition, the resourcing of scrum project can be difficult, if the aim and/or scope of the project changes in between the sprints.

Table 1. Pros and cons of Scrum and waterfall project methodologies

Scrum	Waterfall
+ Scope and the target are not totally clear	+ Project goal is clear and implementation is linear
+ Short-term goals are easy to adopt by students	+ Long-term goals make the big picture easier for students
+ Change process is light	+ Resourcing is usually easy
- Resourcing can be difficult	- Change process is heavy

In 2017, there were 54 customer project implemented in theFIRMA. Approximately one fifth (19 %) of the projects were done using the Scrum. All the Scrum projects were related to web or application design and implementation. Even though Scrum is being adopted to several fields of business, it still seems to be most fluent in its origins, software development. The rest of the projects in 2017, were related to graphical design and editing, testing, training, marketing, hosting and networking, innovation events, gaming and organizing Lego camps and conferences.

DISCUSSION & CONCLUSIONS

In this paper, waterfall vs. agile project management methods in university-industry collaboration projects have been described and discussed. Both disciplinary and interdisciplinary knowledge are needed in order to succeed as a future professional. The ICT project office theFIRMA is a fruitful platform to combine the theory gained in classes to practice in authentic customer projects. Based on the feedback of the students, they feel more confident about their project management skills as well as technical skills after joining different customer projects in theFIRMA.

Even though agile methodologies are rising, still students need to have basic understanding of waterfall and agile project management methodologies. Not only is it important to understand how different methodologies are being used in theory and in practice, but also to understand to project aim, scope and schedule in order to decide the best suitable methodology for a project. In ideal situation, student in theFIRMA participates in different kinds of projects and thus, is able to practice both project management methodologies.

When using Scrum as a project management methodology, it seems that the clear short-term goals and schedules enhance students' commitment to a certain project and thus, enhances learning and motivation. The Scrum methodology suits well especially in R&D projects where the focus is set on rapid prototyping and experimenting. On the other hand, these results only occur if the team of students have been successfully motivated and engaged to Scrum methodology in the kick-off meeting. There are also experiences, where the team of students do not want to use Scrum and thus, they only do it halfway. In addition, experiences in theFIRMA indicates that the best results of using Scrum are at the time when the whole development team has same or almost same kind of schedules. For example, during the work placement when most of the students work in theFIRMA full-time. Scrum methodology emphasizes close co-operation throughout the project and it is only ideal to implement, if the team has similar schedules.

Waterfall project management methodology is more traditional and thus, more easy to adopt. For linear projects the waterfall methodology suits the best. In addition, clear milestones make it easier for students to understand the big picture of the entire project. However, if the project takes several months to implement, there is always a risk that students change or customer is busy with the daily business. It is harder to engage and motivate students for the project, when they jump in during the project. In a sense, the project timeframe should be planned in a way that there is enough time for the possible delays.

Currently, there are no suitable measurement tools to measure and compare the effectiveness of the project management methodologies used in theFIRMA. In addition, each project and each customer are different, so the comparison of using different project management tools and to compare the effectiveness is quite hard to implement.

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BIOGRAPHICAL INFORMATION

Marika Säisä is a project manager in the ICT unit of Turku University of Applied Sciences. She holds a Master of Science in Technology degree from University of Turku (Finland). She is responsible project manager in theFIRMA, mainly concentrating on customer relations and mentoring students with customer projects. She has participated in several national externally funded projects. Currently she works as a project manager in Inside the Box and Hot Potato.

Katariina Tiura is an engineering student in the ICT unit of Turku University of Applied Sciences, majoring in Information and Communications Technology. Besides her studies, she has been an active student in theFIRMA, working as a student CEO and student project manager. Currently she works as a student project manager in Inside the Box project.

Janne Roslöf is a Head of Education and Research (ICT) at Turku University of Applied Sciences. He holds a D.Sc. in Process Systems Engineering and a M.Sc. in Chemical Engineering from Åbo Akademi University (Finland), and a M.A. in Education Science from University of Turku (Finland). He has participated in several national and international educational development assignments. Currently, he is a member of the national Engineering Education working group of the Rectors' Conference of Finnish Universities of Applied Sciences, as well as the Technology Industry and Services anticipation expert group of the Finnish National Agency for Education.

Corresponding author

Marika Säisä
Turku University of Applied Sciences
Joukahaisenkatu 3
20520 Turku, FINLAND
+35844 907 2080
marika.saisa@turkuamk.fi

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ENGINEERING EDUCATION PARADIGM SHIFT IN METROPOLIA UAS

Jukka Jonninen, Antti Piironen, Heikki Valmu

Metropolia University of Applied Sciences, Finland

ABSTRACT

Simultaneous changes in decline of public funding and new metrics how universities are compared caused a financial crisis especially to the field of engineering education. For this reason, Metropolia University of Applied Sciences implemented two year long MeTeLi-project to re-think the engineering education for the following financially challenging years and still maintain the high quality of the education. The MeTeLi-project took place between 2011-2013 and caused a major paradigm shift in Metropolia's engineering education. A great emphasis was put into the first year studies, integrated learning, co-teaching, and project based learning principles. During the re-design process, the CDIO Standards provided excellent answers to numerous practical questions. This paper summarizes the results of the MeTeLi-project and analyses how this transformation affected on the metrics.

KEYWORDS

Government funding, Integrated learning, Rethinking engineering education
Standards: 3, 4, 5, 7, 8, 9, 10,

INTRODUCTION

Due to economic recession the public funding for universities of applied sciences has declined about 19% since year 2009 in Finland. At the same time the ministry of education came up with new metrics on how to measure and compare the performance of the institutes. The model that the ministry of education uses to fund the universities of applied sciences was modified to be solely based on these metrics. In addition, the Finnish Ministry of Education decided also to change the structure of higher education by ending the regulation of degree programmes and introducing a new term of "educational provision". These changes caused big challenges especially to the field of engineering education. Therefore Metropolia University of Applied Sciences implemented two year long MeTeLi-project to re-think the engineering education for the following financially challenging years and still maintain the high quality of the education.

The MeTeLi-project took place between 2011-2013 and caused a major paradigm shift in Metropolia's engineering education. A great emphasis was put into the first year studies, integrated learning, co-teaching, and project based learning principles. During the re-design process, the CDIO Standards provided excellent answers to numerous practical questions. The plans were put into practice on fall 2014 when the total number of degree programmes was significantly reduced by merging the old degree programmes (Valmu, 2014). It was decided by the pedagogical management board of the university that the new curricula are based on a modular structure and the pedagogy is based on collaborative teaching and learning (Barkley, 2006). This paper summarizes the *results* of the MeTeLi-project and analyses how this transformation affected on the metrics.

CHANGING ENVIRONMENT

Finnish Ministry of Education introduced educational provisions in order to simplify the structure of higher education degrees. Before the change all university degrees were organized as degree programmes, which were agreed with the Ministry of Education every 4 years.

The legislation evolved to give the universities more autonomy. Each university currently have their educational provisions, which permit to grant higher education degrees up to a predefined number of students. Old degree programmes are now part of a provision, and universities can start new, end old, or change existing degree programmes as long as the number of graduates studying in each educational provision does not differ from the contract with Ministry of Education.

In Finland most of the funding of the Universities of Applied Sciences comes directly from the Finnish Ministry of Education. Due to economic recession, the level of this funding has been on a decline since 2012 and will settle to about -22% by 2020 as shown in figure 1.

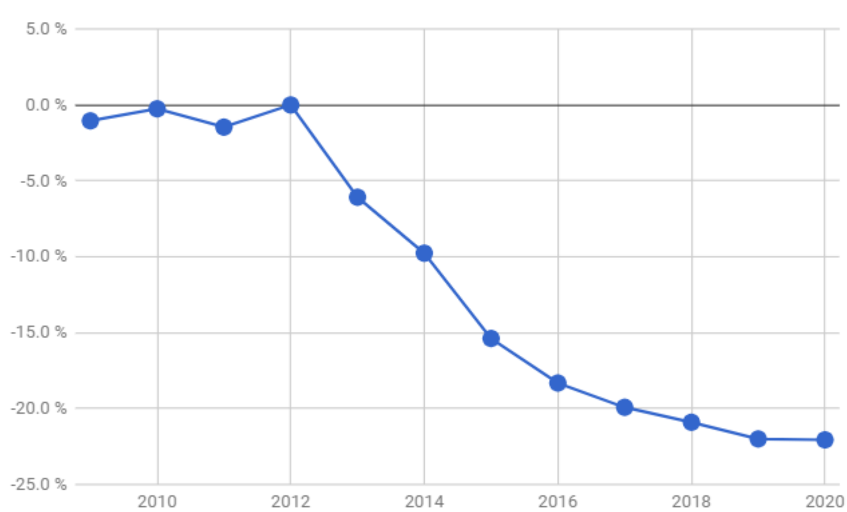

Figure 1: Funding decline of Finnish Universities of Applied Sciences, adjusted to inflation

Previously the funding was based on the number of degree students (70%) as well as the number of graduates (30%). Currently the funding is still based heavily on the number of graduates (40%) but no longer on the total number of students (see figure 2). Instead the funding is based on the number of students making more than 55 ECTS credits per study year of the 60 ECTS total (Minedu, 2017). Fundamentally this ment transformation from input-driven system to output-driven system. Notice that the funding metrics is used only on distributing the government funding between the universities of applied sciences, and the institutes are budgeting the final sum internally using their own rules.

The universities want to improve the student progression in order to make sure that the students make all the courses in time to fulfil the funding criteria. The results in that respect have been relatively poor in the past, since the studies in the engineering degree programmes have been rather flexible and therefore it has been possible for the students to leave some courses to be completed in the future semesters instead of completing all the courses in due time. The curricula of the engineering degree programmes in Metropolia have been previously based in small courses of 3 ECTS credits only and if the students have two of such courses a year pending, the funding criteria is not met.

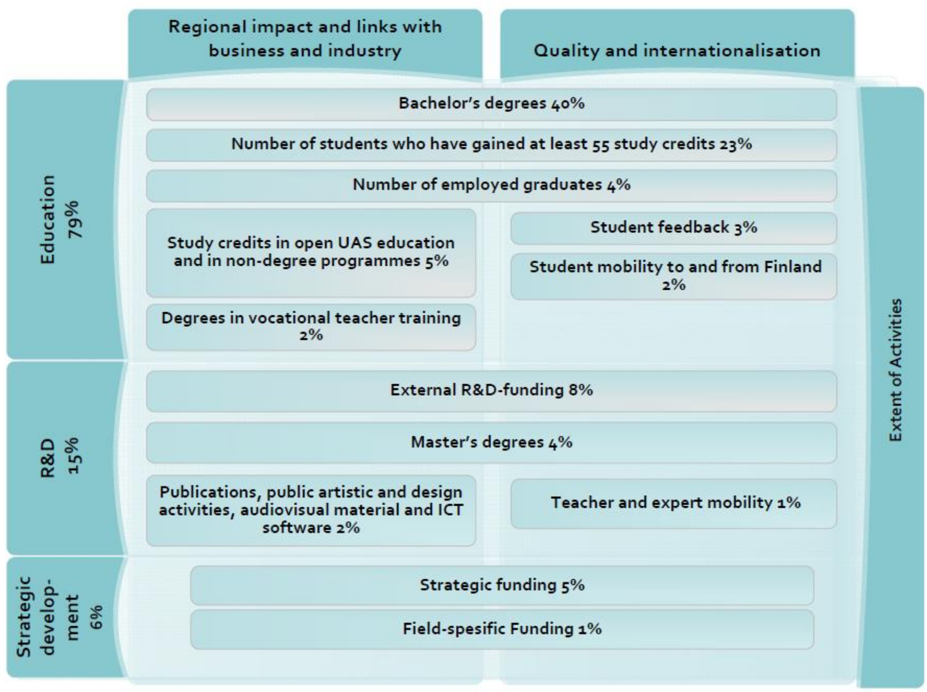

Figure 2: Finnish University of Applied Sciences funding (MinEdu, 2017)

MeTeLi Project

The changing environment prompted an urgent need to find solutions for the evolving challenges. The calculations showed that the new funding metrics would hit hardest the field of technology mainly due to high drop-out rate and slow study progress of students. At the end of year 2011, the Metropolia Management Board decided to invest to an internal development programme MeTeLi (Metropolia Tekniikka ja Liikenne = Metropolia Technology and Transport), which was divided into four main work packages:

1. Vision, strategy, and action plan to improve the results on the most important funding metrics. The target was to create a clear, tangible, and operational image as a basis of Metropolia Field of Technology strategy, set targets for funding metrics 2016, and create action plan how to achieve the target.

2. Educational provisions and operational model for year 2014. The target was to find a model on how the engineering education will be organized. The new model had to be implemented starting fall 2013 and be ready for new student entrance on fall 2014.

3. Teaching, learning, and know-how. The target was to update the engineering education to define a common foundation, common structure for the engineering syllabi, and common elements of education. In addition, another important target was to start a long-term development to clarify the pedagogical choices, develop flexible assessment methods, create dynamic study paths, and find new ways to organize courses to support new learning methods and improve the study progress.

4. Regional cooperation with industry/stakeholders, and constant development. The target was to create operational models to cooperate more closely with regional stakeholders, develop continuous education, and improve the R&D efficacy as an engine of creating new knowledge.

IMPLEMENTATION

The MeTeLi project was completed at end of year 2013 and the engineering education went through a major overhaul during the following year. All Metropolia's 29 engineering degree programmes were merged in that process into 7 educational provisions. For example, the degree programme of Electrical Engineering and the degree programme of Automation Technology were merged and the first students started their studies in the new degree programme of Electrical Engineering and Automation Technology (tuition in Finnish) in August 2014. Also degree programme in Health Technology was merged with degree programme in Information Technology. The new curricula of degree programmes were linked to the curricula of other engineering degree programmes in order to offer efficiently multiple specialization options in the students' study path (Valmu et al., 2014).

Further improvement was still necessary and since the curricula had to be renovated in 2014, it was decided that all the courses will be organized in larger entities of 5-15 ECTS credits based on collaborative teaching and learning and continuous assessment. Most of the engineering students currently study their first year by taking four 15 ECTS courses implemented as project based integrated learning experience. Each course is built around a Conceive-Design-Implement topical task, which works as learning environment for mathematics, physics, and professional topics as well as communication and group working skills.

Table 1: Changes in Metropolia UAS 2012-2016

	Before	**After**
Funding based on	the number of students and graduates	production based metrics
Degree granted by	Degree Programme	Educational Provision
Development cycle	Academic year	Calendar year
Organization	Degree programmes with common management resources	One year on matrix, and then changed to educational provision based line organization
Pedagogy	short courses with single topic	integrated learning in larger modules
Courses taught by	one teacher	team of teachers

RESULTS AND DISCUSSION

The actions planned during MeTeLi-project showed some good progress on the funding metrics point of view. For example, in the old programmes of Electrical Engineering, Automation Technology and Electronics the number of first year students fulfilling the funding criteria of 55 ECTS study points was even smaller than 50% in 2012. When the new funding principles were announced in 2012, many actions were taken within the old curriculum as well. The teaching staff was encouraged to use continuous assessment instead of the end exams, alternative resit options were given to the students etc. By these means the number of first year students fulfilling the criteria in these three programmes was raised above 70% in 2013 (Valmu et al., 2015). Similar very promising results were also found on other engineering programmes who rearranged the curricula to larger course entities and truly focused on course integration, continuous assessment, and cooperative teaching and learning. Unfortunately those engineering degree programmes and departments who followed the new paradigm only at minimum level are have not improved basically at all and are now facing very difficult financial challenges.

Figure 3 A shows how the percentage of engineering degree students achieving full 60 ECTS/year for Metropolia and other UAS for years 2012 and 2016. This comparison indicates that Metropolia engineering education has improved students' performance more than the other universities of applied sciences. However, when we are looking at the 55 ECTS/yr comparison (figure 3 B), we can see that the other universities of applied sciences started improving earlier than Metropolia. There seem to be about 1-1.5 year time shift between Metropolia and others, which requires more detailed analysis than reported in this paper. On the other hand, while the others have reach their saturation point at year 2015, we cannot yet see where Metropolia's results will settle.

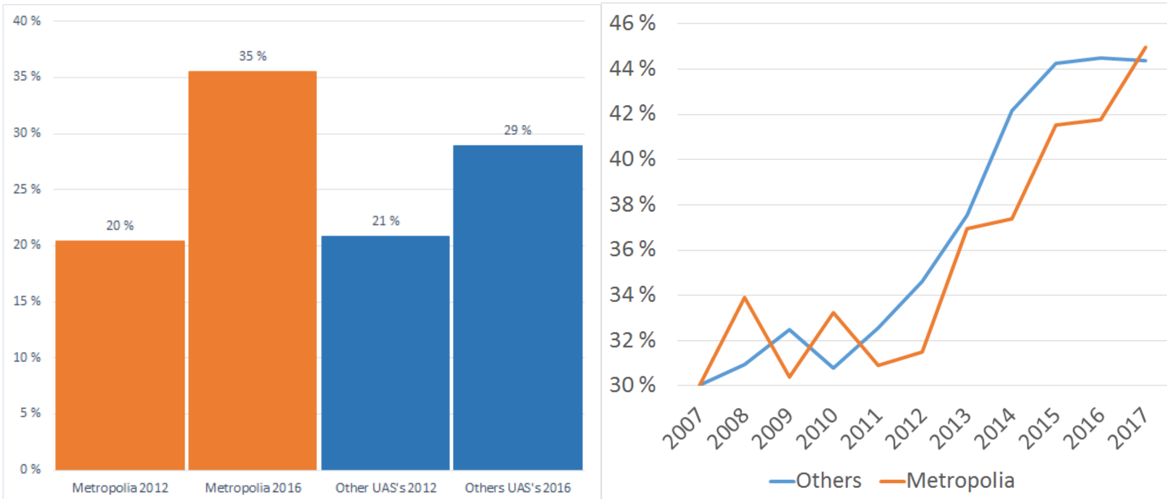

Figure 3. A: The percentage of registered students in the field of technology gathering at least 60 ECTS/yr, B: Percentage of registered enrolled engineering students gathering 55 ECTS/yr or more

The overall situation is more complicated when we start looking at a larger picture. Table 1 represents government funding of engineering field compared to other fields normalized with number of students for years 2012 and 2016. These years were selected since 2012 was the highest ever funding year, and 2016 is the latest year with official statistics (this paper was written before the complete official national 2017 statistics were made public).

This table is formed based on information mainly gathered from Vipunen-portal, which is the main source of education statistics in Finland (Ministry of Education and Culture, 2018). The 2012 funding figures are formed using the Finnish National Agency for Education (2018) statistics of the 2012 UAS funding as a source. The €/student numbers are counted based on the respective funding models used in 2012 and 2016. All of the data is counted based on the ISCED-fields of Information and Communication Technologies and Engineering, Manufacturing and Construction. Some adjustments are made in order to make the statistics comparable to the fields of education that were used in Finland in 2012.

It may be clearly seen that all the Universities of Applied Sciences in Finland are facing hard times in all fields of study. Despite good success in raising the percentage of students who gather at least 55 ECTS each study year, Metropolia UAS is not doing any better than the other universities in terms of total funding. Its financial decline in Engineering is a bit larger than the decline of the other universities. The comparatively large decline of engineering is mainly due to poor results in the external R&D funding- and publications -indicators. Metropolia's Technology is responsible of only 5-6 % of the Finland's technology field results in these indicators compared to 17 % in the case of 55 ECTS. While the MeTeLi-project focused on improving the engineering education, at the same time less attention was paid to improve R&D operations.

Table 1: Government funding (adjusted to inflation) per student calculated from metrics.

University of Applies Sciences	Students 2012		Students 2016		€/Student 2012		€/Student 2016		Ratio (€/S) 2016/2012	
	Tech	Others	Tech	Others	Tech	Others	Tech	Others	Tech	Others
Centria	1 193	2 395	1 017	2 039	7 837 €	5 451 €	7 038 €	5 947 €	-10 %	9 %
Diakonia	0	3 114	0	2 909	0 €	7 944 €	0 €	6 843 €		-14 %
Haaga-Helia	1 744	8 902	1 874	9 101	5 464 €	6 056 €	4 366 €	5 717 €	-20 %	-6 %
Humanistinen	0	1 483	0	1 544	0 €	9 187 €	0 €	8 728 €		-5 %
Häme	3 127	4 676	2 797	4 544	6 054 €	6 358 €	5 621 €	5 013 €	-7 %	-21 %
Jyväskylä	2 496	5 426	2 878	5 190	6 205 €	6 356 €	4 599 €	6 152 €	-26 %	-3 %
Kaakkois-Suomi	2 615	5 948	2 995	6 215	6 855 €	7 462 €	6 401 €	6 211 €	-7 %	-17 %
Kajaani	715	1 425	869	1 433	6 183 €	6 767 €	5 244 €	5 563 €	-15 %	-18 %
Karelia	1 144	2 769	988	2 759	6 681 €	7 485 €	6 027 €	5 890 €	-10 %	-21 %
Lahti	1 500	3 744	1 489	3 541	5 840 €	7 199 €	4 476 €	6 656 €	-23 %	-8 %
Lappi	2 005	4 127	1 833	3 994	6 936 €	6 908 €	5 403 €	5 744 €	-22 %	-17 %
Laurea	716	6 957	733	6 958	5 820 €	7 151 €	4 911 €	6 273 €	-16 %	-12 %
Metropolia	8 066	7 974	8 238	8 359	5 915 €	7 746 €	4 279 €	5 691 €	-28 %	-27 %
Oulu	3 218	5 331	3 404	5 142	6 940 €	6 550 €	4 342 €	5 671 €	-37 %	-13 %
Saimaa	908	2 223	673	2 622	8 045 €	5 981 €	5 654 €	5 720 €	-30 %	-4 %
Satakunta	2 255	3 599	2 145	3 708	6 271 €	6 965 €	4 446 €	5 670 €	-29 %	-19 %
Savonia	2 249	4 197	2 288	4 312	7 268 €	7 240 €	5 253 €	5 431 €	-28 %	-25 %
Seinäjoki	1 458	3 512	1 493	3 332	5 235 €	7 149 €	5 450 €	5 420 €	4 %	-24 %
Tampere	4 122	6 291	4 041	6 192	6 197 €	7 107 €	4 535 €	5 697 €	-27 %	-20 %
Turku	3 638	6 012	3 477	6 044	6 579 €	7 709 €	4 748 €	6 174 €	-28 %	-20 %
Vaasa	1 562	1 984	1 547	1 680	5 866 €	5 852 €	3 567 €	5 095 €	-39 %	-13 %
Arcada	460	1 900	398	2 069	7 859 €	7 010 €	6 038 €	5 760 €	-23 %	-18 %
Novia	1 544	2 213	1 596	2 461	6 799 €	7 700 €	5 459 €	5 538 €	-20 %	-28 %
Total	**46 735**	**96 202**	**46 773**	**96 148**	**6 384 €**	**6 996 €**	**4 899 €**	**5 888 €**	**-23 %**	**-16 %**

CONCLUSIONS

Metropolia engineering education went through a series of big changes, and used it as an opportunity to modernize education. As a result, the engineering syllabi are now less fragmented, which shows up in some degree programmes as improved student progress when measured by number of students reaching 55 ETCS/year. However, based on the results on funding metrics we cannot see clear evidence for success, since the other universities of applied sciences have also improved their outcomes. Comparison between different fields inside Metropolia reveal that the engineering education has been able to maintain the same rational decline as the other fields in average.

The final level of improvement in both student progression and number of graduates in the engineering degree programmes in Metropolia UAS is still to be seen, since the curriculum change (the paradigm shift) was done in early 2014 and the first students started their studies based on the new pedagogy in late August 2014. These student groups are to graduate after the spring term of 2018 and already it seems quite clear that many degree programmes will reach their all-time records in the number of graduates this year. Most other universities did only minor reforms to improve their results and their improvement seems to be already saturated in 2015 as seen in Fig. 3B when Metropolia UAS is still improving very strongly when the number of students in the new modernized programmes based on the new pedagogy increased constantly until September 2017 (and the results of the last group are first included in the metrics of 2018).

We also can see that the bigger universities of applied sciences have not been able to benefit from their size, but quite opposite: six largest universities of applied science are performing worse than average when compared on the decline of engineering funding results. This study was conducted mainly to see if the big changes planned in MeTeLi project had a positive change in the most important funding metrics, namely 55 ECTS/year and number of graduates. The study also revealed that more research should be done in order to deeply understand how to optimize the funding. In future we are going to do similar analysis also to other funding parameters and find some cure for the funding challenges.

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BIOGRAPHICAL INFORMATION

Jukka Jonninen is a Specialist in the Strategy and Development Unit at Metropolia University of Applied Sciences. He coordinates a forecast network of 21 Finnish Universities of Applied Sciences. The network aims to predict the indicator results that form the UAS funding from the Finnish Ministry of Education.

Antti K. Piironen is a Principal Lecturer of Smart Systems Engineering in the School of ICT at Metropolia University of Applied Sciences. He collaborates regularly with universities in Europe on topics related to joint courses, teacher exchange, and curriculum design. His current scholarly activities focus on the providing professional ICT engineering education using mixture of modern and traditional teaching tools and methods.

Heikki Valmu is the Head of the Department in Electrical Engineering and Automation Technology of Metropolia University of Applied Sciences. His R&D background and teaching activities are focused on Analog Electronics and Microwave Engineering. He is currently as well actively participating a project to redesign the admissions procedures of the Finnish Universities of Applied Sciences.

Corresponding author

Dr. Antti K. Piironen
Metropolia University of Applied Sciences
Vanha maantie 6
FI-02650, Finland
+358-40-555-2871
antti.piironen@metropolia.fi

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PEDAGOGICAL RESULTS: JOINT ENTREPRENEURSHIP COURSE IN ENGINEERING AND BUSINESS SCHOOL

Aderson Campos Passos
Military Institute of Engineering (IME)

Edson Kenji Kondo
School of Public Policy and Government of Getúlio Vargas Foundation (FGV EPPG)

Waldemar Barroso Magno Neto
University Center Unicesumar

Carla Danielle Monteiro Soares
Brazilian School of Public and Business Administration of Getúlio Vargas Foundation (FGV EBAPE)

ABSTRACT

This paper has the objective of testing the effectiveness of a joint course in entrepreneurship carried out by a teaching team from two very distinct schools in Brazil: one school of engineering and one school of business. The joint initiative came in the wake of an effort by both institutions to improve its pedagogical approaches and exactly when both schools were trying new methods of active learning. IME, the engineering school, was implementing CDIO. FGV EBAPE, the business school, was implementing PBL. This paper tests the effectiveness of the joint undertaking by evaluating the perception of the students at the end of the course according to four pedagogical principles, namely *development of attitudes and skills; revealing the students' knowledge in the classroom; striving for deeper understanding so that knowledge is usable; and taking a meta-cognitive approach to make students take control of their own learning*. The results from the survey of former students strongly suggest that the pedagogical methodology used in this joint entrepreneurship course fulfilled all principles and indicated its effectiveness in improving learning.

KEYWORDS

Active Learning, Problem Based Learning, Entrepreneurship Education, Standard 8.

INTRODUCTION

The new technological products and services enchant the youth worldwide. Several young men and women decide to study engineering and business to be part of this new world and contribute to solve an uncountable amount of problems. Beyond this, building a new business becomes an alternative to new graduates compared to the traditional quest for a good job in a well-established company. Hence, *entrepreneurship* becomes a mandatory subject within the curriculum of both engineering and business programs.

The implementation of successful technological business is not an easy task. Among several factors, the specialists highlight the *team building* as one of the most important critical success factors in new companies (Tan & Frank Ng, 2006). In this context, not only the synergy between the company founders is important, but also having complementary abilities. Engineering students and professionals normally deal with technology and know very little about business methods. At the same time, business students and professionals have a lot of knowledge of business, but usually are not able to develop technological products or services to solve real problems. According to these premises, it is reasonable to think that a joint course that puts together students from these complementary courses, business and engineering, will contribute for the development of successful business ventures.

This article describes a joint implementation of an entrepreneurship course between two elite Brazilian schools: the Military Institute of Engineering (IME) and the Brazilian School of Public and Business Administration of Getúlio Vargas Foundation (FGV EBAPE). The main feature of this course is the intense use of active learning as the core pedagogical method. The review of the literature revealed that this work presents a different approach compared to previous articles. Nabi et al. (2017) developed an extensive survey about entrepreneurship in higher education and created an integrated teaching model framework to encompass the entrepreneurship education impact and the underpinning pedagogy. This framework considers three “archetypical” teaching models in higher education, as proposed in Béchard and Grégoire (2005): supply models (normally focused on lectures), demand models (student participation in terms of “exploration, discussion and experimentation” using, for example, library, interactive searches, and simulations), and competence models (based on active learning). The same framework also considers different types of impacts obtained from entrepreneurship education such as entrepreneurial intentions (Barba-Sánchez & Atienza-Sahuquillo, 2018), interest, knowledge, survival of startups and contribution to society. Nabi et al. (2017) suggest that competence model pedagogy is better suited for developing higher level impact and identifying a research gap to explain the reasons for the superior results of such competence models.

Differently from other approaches, this article focuses on the pedagogical results obtained from the application of active learning to address four pedagogical principles. The authors identified in the literature three key findings by the Committee on Developments in the Science of Learning of the National Research Council of the U.S. which have strong implications for the way teaching is done (National Research Council, 2000, p. 26-30). These findings were translated into three principles, namely *revealing the students’ knowledge in the classroom*, *striving for deeper understanding so that knowledge is usable*, and *taking a meta-cognitive approach to make students take control of their own learning*. The authors also selected the *development of skills and attitudes* as an additional factor because of its increasing importance in engineering and business education worldwide and its presence as a core motivation for the CDIO implementation (Crawley et al., 2012).

The authors contend that the joint entrepreneurship program developed by IME and FGV EBAPE was able to effectively cover these four pedagogical principles. This contention is tested through a survey applied to a sample of former students of the course. The authors also believe that this approach contributes to address the research gap identified in Nabi et al. (2017), mentioned in the previous paragraph.

Another important topic in this article is the description of non-intended results obtained from the relationship between IME and FGV EBAPE at this course. FGV EBAPE teachers had the opportunity to learn about the CDIO implementation at IME and could foresee the possibility of transferring engineering education best practices to the business education environment and vice-versa.

Considering the main features described above, the article is structured as follows: a) Explanation of the partnership between IME and Getúlio Vargas Foundation (FGV); b) Description of the course itself highlighting the PBL classes; and c) Evaluation of the pedagogical results of this course through a survey applied to 40 students. At the end, the article briefly discusses the non-intended results mentioned above and closes with concluding remarks.

PARTNERSHIP BETWEEN IME AND FGV

The Memorandum of Understanding (MoU) between FGV and IME was established in August 2014. Since that moment, several activities have been running with fruitful results. IME students attend graduate and undergraduate courses at FGV and there is also faculty exchange. The Brazilian School of Public and Business Administration (EBAPE) is one of several schools that belong to FGV. Hence, the MoU also comprises activities that have been carried out with other schools. FGV also provided valuable support in IME's strategic planning in 2015, and e-learning support for IME students who were abroad participating at international internships. Regarding specifically the Entrepreneurship course, its joint implementation met FGV and IME needs, but was particularly driven by the Brazilian Army (BA) Commander's view that entrepreneurship could help modernize the Army.

IME and FGV have been discussing further joint activities. After the success of the entrepreneurship joint course, representatives of both organizations have been planning other collaborative efforts in research and the creation of a joint graduate and undergraduate programs.

COURSE DESCRIPTION

The Entrepreneurship course, taught by teachers from both institutions, was divided into two main parts. In the first half of the course, several entrepreneurship concepts were presented for discussion among the students, focused on the *lean startup* method (Blank and Dorf, 2014). This part also included the study of topics about business model canvas, strategy and marketing, in addition to lectures and discussion with angel investors. In the second half, the students were tasked to develop their own startup in groups of four or five, using the methods learnt in the first half.

The main goal of the first part (half) was to promote real-life case discussions and demonstrate their correlation with the main theories in this field. This part aimed at familiarizing the students with developing tools, analyzing customer feedback and developing the product or service. Thus, the students should be able to understand the importance of a real-world learning system to develop the competence of testing recursively, in a trial and error process, which would help them to fine tune the product based on market expectations. The course meetings in the first part were held once a week and were conducted using the Problem Based Learning (PBL) method. For the retention of the main concepts, the teachers applied, beyond the PBL, other active learning methods, such as group discussions, extra-class activities and lectures with practitioners and experts such as funding agency officials and real investors.

In the second part of the course, the students organized themselves into groups evenly comprised by students from IME and FGV EBAPE. The groups were challenged to create a startup and make, at the end of a seven-week period, a pitch for real investors from the local entrepreneurial ecosystem. During this time, the groups were advised by the teachers and encouraged to “get out of the building” to test their solutions against the needs of real customers.

At the end of the course, the students should have enough knowledge to develop the process of creating a startup on their own. Actually, the first cohort had one group which successfully launched the startup at the pitch presentation class, and after one year already expanded its activities from Rio de Janeiro to São Paulo. The second cohort taught last semester had one startup sold to a large company for a significant sum of money.

Class using PBL

As previously mentioned, the first half of the course was conducted on weekly meetings. A workbook, with the underlying problems, was developed to prepare and guide the students for the classes in PBL format. The problems had to stimulate students’ curiosity and engagement and represented a reference to raise a set of questions that would guide the self-study. In view of that, four problems were developed for debate, incorporating the entrepreneurship topics selected by the teaching team. The students were advised to prepare for debate covering the bibliographic material provided, as well as other materials considered important by the students themselves.

The teaching team applied the PBL method in seven steps, as proposed by Moust et al. (2013, p. 22):

- Step 1: Clarify unclear terms and concepts in the problem text
- Step 2: Define the problem: What exactly needs explaining?
- Step 3: Problem analysis: Produce as many ideas as possible
- Step 4: Problem analysis: Arrange the ideas systematically and analyse them in-depth
- Step 5: Formulate learning goals
- Step 6: Seek information from learning resources
- Step 7: Synthesise and apply the new information

The students received one problem every week. The students tackled the problem through three phases each week: phase 1) Pre-discussion, which comprised steps 1 to 5 and took place during the second half of class time; phase 2) self-study, which was represented by step 6 and took place outside the classroom; and phase 3) Post-discussion, which was represented by step 7 and took place during the first half of class one week after the pre-discussion class.

Because the PBL method requires intense interactions, the class size is small. Therefore, the class was divided into four subclasses, with about 15 students each. The class is usually run by one teacher, but thanks to a large number of teachers volunteering to participate in the innovative undertaking, the subclasses could afford to have two teachers each.

The mix of students in each subclass changed every week. The students were assigned to subclasses by an algorithm which ensured that each student would meet all 60 students through the four sessions of the first half of the course. This procedure promoted greater integration and ensured that, by the end of the four sessions, all 60 students had met each other in a subclass. The system enabled constant exchange between students and teachers, offering them the opportunity to be in contact with all people involved in the learning process. Each session is conducted by a leader and a secretary, and both are chosen by the students themselves on a rotating basis. The leader's role is to conduct the discussion and connect the content studied in the bibliography with the real life problem. The leader should strive to produce a lively and balanced level of participation by all students. The secretary is responsible for taking notes and synthesizing ideas discussed in the meeting.

It must be emphasized that all the students were required to be prepared for the discussions by reading the indicated bibliography and were evaluated by the teachers at the end of each class. Teachers are responsible for concluding the discussion, reporting on the strengths of the group, pointing out the improvement (when applicable) and the academic performance of each student.

In each class, a participation grade was assigned, ranging from 0 to 1, which had a multiplicative effect on their mid-term evaluation. Although the grade was given only in the post-discussion, it took into account the student's performance in the pre and post-discussion for each "problem". Students who did not attend the class would be given 0 (zero) on that meeting. Nevertheless, students were required to attend a minimum percentage of classes.

Preparation, presentation, and participation were the bases for the grades in each class.

Application: building startups

The startup construction took place in the second half of the course aiming at applying the content studied in the PBL classes. At the beginning of this phase, the students presented a seven-minute pitch with the outline of their proposed business model for the startup. The teachers collectively validated the proposals, suggesting the necessary adjustments and defining the next steps for the development of the startup according to the lean startup method (Blank & Dorf, 2012). The advisory sessions started after this validation.

Each group of students, formed by a maximum of five and comprised by at least two students from each institution, was advised by two teachers, who assumed the role of tutors from that moment on. Throughout this process, the students carried out the following activities for the project development: market analysis (including customer discovery); business hypotheses and validations; pivoting; customer development and validation; supplier study; marketing plan; operational plan; and financial plan. In addition, students held meetings with potential clients and partners, carried out consumer research, and talked to investors who assisted them with market experience and knowledge of different scenarios that could affect the success of a new business.

At the end of this stage, the groups presented their pitches in an event open to the general public and special guests. The startup projects were evaluated by a panel of investors who evaluated the projects for future investments.

PEDAGOGICAL RESULTS

As mentioned in the Introduction, the pedagogical results presented in this article are related to four pedagogical principles proposed by the authors on the basis of studies carried out by Crawley et al. (2012) and the Committee on Developments in the Science of Learning of the U.S. National Research Council (National Research Council, 2000).

The four pedagogical principles can therefore be described as the following: a) development of attitudes and skills; b) revealing the students' knowledge in the classroom; c) striving for deeper understanding so that knowledge is usable; and d) taking a meta-cognitive approach to make students take control of their own learning. This section describes how the pedagogical principles are related to the application of the PBL method and other active-learning practices held during the course.

Development of attitudes and skills

The PBL section is a formal meeting conducted and reported by students but supervised by a teacher. During these sections all the students can express their ideas about the subject they learned during the previous week. Additionally, the students must listen carefully to the speech of their colleagues to make suitable comments about the questions that must be answered. Hence, it is possible to say that the PBL sections contribute to the development of oral speech, active listening and team working.

Revealing the students' knowledge in the classroom

The teacher must listen carefully to the student conclusions about the subject of the featured problem. In this moment the preconceptions and misconceptions are revealed and the teacher can intervene and make comments. Comparing the PBL section with the traditional lecture, the PBL section provides many more opportunities to express his opinion about the subject and to actively use the theoretical knowledge acquired during the self-study time outside the classroom.

Striving for deeper understanding so that knowledge is usable

The choice of building a limited curriculum with a deeper approach is normally hard for the teachers. However, research reveals that this approach contributes to the construction of a well-structured knowledge schemata. Additionally, this principle emerges from the research that compares the performance of experts and novices in learning and transfer of knowledge. This principle was used in the syllabus preparation. Several topics (lean startup, business model canvas, design thinking and blue ocean strategy) and books were initially selected. However, the teachers decided to focus on the lean startup method (which uses the business model canvas) to increase the students understanding about this topic and simplify the knowledge transfer for different situations.

Taking a meta-cognitive approach to make students take control of their own learning

The word meta-cognition is reflexive: thinking about your own thinking. In this context, it is related to development of the critical thinking about what each student learned individually. Once the PBL sections create an opportunity for the students to express their ideas and to listen to the other colleagues' knowledge about the featured problem, each student can make a self-criticism and look for additional learning, if necessary.

Questionnaire and its objectives

The questionnaire intended to evaluate the pedagogical results of the Entrepreneurship course according to the principles described above. The course was offered twice so far, and approximately 90 students attended the course in total> A sample of 40 former students responded the questionnaires. Table 1 presents the questions and the answers.

Table 1. Questionnaire results

Question #1: Do you believe that the application of PBL method in the entrepreneurship course ***contributed*** for the development of your interpersonal skills:			
Yes – 90%		No – 10%	
Question #2: Which interpersonal skills were developed during the PBL classes (more than one option may be selected):			
Team Working	– 55%	Oral speech	– 87.5%
Active Listening	– 72.5%	None	– 2.5%
Question #3: Do you believe that the PBL classes provided you the opportunity to expose your knowledge about the featured topics?			
Yes – 90%		No – 10%	
Question #4: Do you feel able to put into practice the things you learned in the Entrepreneurship course?			
Yes, certainly	– 42.5%	No, I cannot remember anything	– 5%
Yes, but only if I could review the subjects	– 52.5%	No, it is not possible to apply this subject	– 0%

Questions #1 and #2 have to do with the first principle: *development of attitudes and skills*. It is clear that most of the students believe that the PBL sections contributed to the development of their skills. Moreover, it is important to highlight that all the students had another chance to practice *team working* and *oral speech* in the second part of the course, when they needed to build a startup and present their work for investors in a pitch section.

Question #3 is related to the second principle: *reveal the students' knowledge in the classroom*. It is clear that most of the students believe that they had the chance to reveal what they knew about the topic. Hence, there is evidence that the PBL method contributes to improve the learning process. It is important to notice that the methodology tasks teachers to correct substantive mistakes when the teacher sees a lack of time for the students themselves to correct a mistake during a specific class.

Question #4 is related to the third and fourth principles: striving for deeper understanding so that knowledge is usable, and t*aking a meta-cognitive approach to make students take* *control of their own learning.* The question itself measures the student's confidence to transfer the acquired knowledge to practical situations, and results from the entire course and not only from the PBL classes. The answers show three levels of learning/confidence: a) extremely confident, b) confident and c) not confident. These are outstanding results for the teacher group (95% of the students feel confident to apply the knowledge acquired in the course) and show high usability of their knowledge after the end of the course.

ASSESSMENT OF LEARNING

The PBL method, with the pre-discussion class and the post-discussion class on the same topic, allowed the teachers and students to clearly view the progress between two sessions. We specifically monitored the students and the results were the following.

Problem 1: It is the actual description of two girls who decide to start a business in their last year of a management undergraduate program. In PBL, the description is purposefully incomplete, terms regarding solar energy and solar panel production are used as if addressing an audience of experts. Therefore, most students have scant idea of the terms and the issue and they start in the pre-discussion class by asking as many questions as there are doubts. Then, they are given one week to do research and to spend time in groups for developing the answers. One week later they discuss which are the best answers in the post-discussion.

Table 2. Analysis for Problem 1

Listing and Discussion of unknown topics Aug 11th 2017 (Pre-discussion)	**Answers developed by students in Aug 25th 2017** (Post-discussion; summarized)	**Observed objective learning** (Teachers meet right after class to evaluate the learning by the students as a whole)
Q1) What is a startup?	A1) Firms with an innovative business, scalable, and generally with a base in technology.	O1) Starting from mostly no idea, in one week students understood the concept and presented several examples discussed in groups.
Q2) What are unicorns?	A2) Unicorns are startups with Market value upwards to a billion dollar. Examples are Facebook, Uber, Airbnb, Spotify, among others. Because solar panels represent clean and sustainable energy, relatively low cost and plentiful in Brazil.	O2) Had no idea. In a week they were using “unicorns” to describe potential startups.
Q3) Why produce solar panels?	A3) Main opportunities: photovoltaic system integrators, various consulting and advisory services (environmental, legal, tax, land, financial, solar resource evaluation, technical / engineering, training and qualification), certification services, etc.	O3) From not knowing much about solar energy in Brazil, in 1 week they understood the merits of clean energy and the relative advantage vis-à-vis other countries.
Q4) What business opportunities are there in this area?	It is the development of actions that allow man to meet his current needs without compromising the future of the next generations.	O4) They also understood the existence of many related areas to be exploited as business.
Q5) What is sustainability?	As mentioned in the Brundtland Report, Our Common Future: "Essentially, sustainable development is a process in which resource exploration, investment direction, the path of technological development and institutional change are in harmony and improve men's ability to have their needs and aspirations met both now and in the future."	O5) From a general idea of what means to be sustainable, the students were able to pinpoint the origins and precise meaning of the term.
Q6) What is the canvas method?	Business Model Canvas is a tool developed by Alex Osterwalder that helps the entrepreneur map and model his business, helping him in the process of creation, differentiation and innovation. It provides an integrated view of the business being proposed. The Business Model Canvas is divided into 9 areas: Client; Relationship; Channels; Value Proposition; Activities; Resources; Partners; and Sources of revenue.	O6) From not knowing anything, they discovered that it was a very useful way of understanding a business model through nine dimensions, with the value proposition at the center, how to enchant the customer, how to build an essential infrastructure, and how to make it produce income.

Problem 2: This problem uses the same underlying story about the girls planning the launch of a startup for production solar panels with social inclusion. The problem mentions some business tools that may be used to analyze the conditions to implement the new venture and guide the students to raise questions, including the main topic of this problem: the Customer Discovery stage in the development of a startup.

Table 3. Analysis for Problem 2

<table>
<tr><th>Listing and Discussion of unknown topics Aug 25th 2017 (Pre-discussion)</th><th>Answers developed by students Sep 01st 2017 (Post-discussion; summarized)</th><th>Observed objective learning (Teachers meet right after class to evaluate the learning by the students as a whole)</th></tr>
<tr><td>Q1) What is Porter’s Five Competitive Forces method?</td><td>A1) This method helps the companies to analyze the market and the competitors. The five forces are: Rivalry among existing competitors; Threat of new entrants; Bargaining Power of Buyers; Threat of Substitute Products or Services; and Bargaining Power of Suppliers.</td><td rowspan="5">O1) From a general idea of this concept, students could relate Porter’s Five Forces concepts with the founding of new ventures.

O2) Starting from mostly no idea, the students could contextualize the concept of market in perfect competition within the entrepreneurial environment.

O3) The market estimation techniques were unknown for IME students. FGV EBAPE students could compare the technique proposed in the textbook with their previous marketing course.

O4) The Lean Startup’s Customer Discovery was unknown for the students. The post-discussion was rich to put together previous and new knowledge in the entrepreneurial setting.</td></tr>
<tr><td>Q2) What is a market in perfect competition?</td><td>A2) It is a theoretical kind of market that has a great number of companies and buyers and, for this reason, neither companies nor buyers can influence the equilibrium price.</td></tr>
<tr><td>Q3) How can we estimate the market size?</td><td>A3) One possible approach is to define the total market, the addressable market and the accessible market for the startup products and services. To be successful in the estimation you should follow the rules: a) be generic first and specify your market afterwards, b) be realistic, c) use reliable data, d) consider possible future changes.</td></tr>
<tr><td>Q4) How can we discover potential customers?</td><td>A4) Searching and interviewing people that are possibly interested in the product or service.</td></tr>
<tr><td>Q5) What is the downstream of the production chain?</td><td>A5) It is the part of the logistic chain that takes the product to the final customer.</td></tr>
</table>

Problem 3: Following the same idea of the previous problem, the Problem 3 continues telling the same underlying story about the solar panels entrepreneurs. The story evolves showing their difficulty to meet the customer needs and guide the students to search for deeper understanding about the Lean Startup and the Customer Validation stage.

Table 4. Analysis for Problem 3

Listing and Discussion of unknown topics Sep 15th 2017 (Pre-discussion)	**Answers developed by students Sep 29th 2017** (Post-discussion; summarized)	**Observed objective learning** (Teachers meet right after class to evaluate the learning by the students as a whole)
Q1) What means business model pivoting?	A1) Pivoting means the implementation of changes in the business model. It normally happens when some problem is observed during the contact with customers.	O1) Starting from mostly no idea, in one week students understood the Lean Startup method and how it uses other important business concepts.
Q2) What is customer validation?	A2) It means testing the proposals obtained from the prospective customers. The second step of the Lean Startup's C*ustomer Development.*	
Q3) What is the relationship between the customer validation and the MVP?	A3) It is very important to obtain an MVP that satisfies the customer needs. The MVP will be offered as an initial product to the customers, during the *Customer Development*. Its acceptance is an indication that the improved product will be also successful.	O2) The students learned a lot in the post-discussion comparing Porter's Generic Strategies with the Blue Ocean Strategy.
Q4) What is the relationship between the Blue Ocean Strategy and the Porter's Generic Strategies?	A4) Porter says that it is not possible to have both product differentiation and low cost. The Blue Ocean Strategy suggest that it is possible and must be chased by the companies.	O3) The concept of MVP was unknown for most of the students and they could understand the importance of this initial version of the product for the *customer validation* stage.
Q5) When is relevant the change of product design?	A5) a) to improve product delivery, b) to enhance the market share, c) to reduce production costs, d) to follow the needs of most customers.	

The group of teachers analyzed the knowledge achievements in each session. This tool was important to catalog the learning results, and monitor the quality of the PBL problems proposed. This step was important to prepare the students for the startup construction.

NON-INTENDED RESULTS

As experienced by the Olin College of Engineering and Babson College that purposefully built the campus adjacent to each other, just proximity is not enough for a desired and expected synergy to occur. As the Provost of Olin College explained to one of the authors who visited them this year, the differences in culture between Olin and Babson were significant and they had not anticipated that. Curiously, the results attained by this joint entrepreneurship course had great success not only among the students, as shown by the survey results, but also among the faculty involved. The initial objective of the joint course was to respond to the request made by the Brazilian Army Commander to instil some entrepreneurial thinking on to rule abiding but less entrepreneurial military personnel.

Surprisingly, in quick succession, one successful business startup in the first cohort was followed by an even more successful business startup in the second cohort.

CONCLUSION

The pedagogical results achieved by this joint initiative through an entrepreneurship course present an interesting evidence that this undertaking was a clear success according to the four principles considered: a) development of attitudes and skills; b) revealing the students' knowledge in the classroom; c) striving for deeper understanding so that knowledge is usable; and d) taking a meta-cognitive approach to make students take control of their own learning.

In other words, it suggests that there are significant gains to be obtained by joint partnerships between business and engineering schools if carefully designed along the pedagogical principles tested in this article. Further studies with larger samples are needed to confirm this initial finding.

As described in this article, most students have the first formal contact with the subject in this course. Additionally, although the course is only two years old, the authors are proud to have two successful former-student startups in operation, and one is being traded to be bought by a larger company. Its founders will become millionaires before graduating.

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BIOGRAPHICAL INFORMATION

Aderson Campos Passos is D.Sc in Electrical Engineering, belongs to IME since 2005 and teaches courses in the interface between business and engineering: entrepreneurship, project management and innovation management. He is part of the team that is responsible for the implementation of pedagogical good practices at IME. His current research interests include innovation systems, university management and engineering education.

Edson Kenji Kondo is PhD in Public Policy from Harvard University and Industrial Engineer from Sao Paulo University. Past positions include Member of the Deliberative Board of the National Council for S&T of Brazil, Chairman of the PhD and Post-Doctoral Program at the United Nations University, Board Member of the Institute of Strategic Leadership of Japan, President of the American School in Brasilia, visiting researcher at the Center for Business and Government at Harvard Kennedy School and at the National Institute for S&T Policy of Japan. Currently serves as the Vice-Dean of the School of Public Policy and Government of the Getúlio Vargas Foundation in Brazil. His current research involves entrepreneurship in government and in sustainable business.

Waldemar Barroso Magno Neto was IME provost between 2014 and 2017, when started the CDIO implementation. In this same period, the joint course of entrepreneurship was initiated and had him as part of the teaching team. Currently, he is member of the implementation council of the new engineering program in blended learning format and teacher of entrepreneurship, both at the University Center UniCesumar.

Carla Danielle Monteiro Soares is teacher and academic coordinator of the undergraduate management program at FGV EBAPE. She concluded her D.Sc. at FGV EBAPE, conducting research on e-Government, Digital Inclusion and Information and Communication Technology. She also concluded her M.Sc. in Business Administration at FGV EBAPE.

Corresponding author

Dr. Aderson Campos Passos
Military Institute of Engineering
Praça General Tibúrcio 80, Praia Vermelha
Rio de Janeiro, RJ, Brazil, 22290 270
55-21-2546-7085
aderson@ime.eb.br

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INVOLVING STAKEHOLDERS IN CDIO PROJECTS

Jacob Nordfalk, Ian Bridgwood

DTU Center for Bachelor of Engineering Studies, Technical University of Denmark

Mads Nyborg

DTU Compute, Technical University of Denmark

ABSTRACT

The Technical University of Denmark has implemented the CDIO standards and principles in all of its B.Eng. courses since 2008. In order to increase innovative skills and to educate engineers who are capable of directly fulfilling the needs of Danish industry, the curricula of the B.Eng. Software Technology (SWT) and B.Eng. IT and Economics (ITOE) have recently been revised (Nyborg et. al. 2015). This revision has focused upon combing the best of the existing educations which are rooted in a practice oriented development environment and by strengthening the involvement of stakeholders in general. The involvement of stakeholders is a central tenet in the implementation of the CDIO framework and can be challenging to accomplish. This is even more pronounced when considering external stakeholders.

We present a roadmap that shows how external stakeholders can be successfully involved in undergraduate courses. Already from the beginning of the 2nd year studies, students and stakeholders are engaged in significant collaboration on real world projects. The project ideas are proposed by external stakeholders and come from the field of mobile application development.

The product development process has been designed and developed to closely reflect the processes and challenges that the students will meet when employed in industry after graduation. This process includes the challenges and uncertainties that occur in real life with real customers and stakeholders. The courses involved are compulsory courses which are offered annually on the third semester. The courses have now been held three times and after each completion the process and content have been evaluated and refined in accordance with the feedback received from the students and stakeholders involved.

The involvement of stakeholders from the very beginning of the projects provides an environment for real world development processes including requirements elicitation and design build experiences utilizing industry standard tools and cutting-edge technologies. This approach achieves the involvement of external stakeholders within the full CDIO framework, clearly establishing CDIO as the context for engineering education (CDIO Standard 1). We encourage engineering educational institutions to implement the roadmap as a way of involving stakeholders within the CDIO framework. This article will present details and

important considerations on each step of the roadmap as well as findings and insights gained.

KEYWORDS

CDIO-based study programs, Stakeholder involvement, Innovation, Standards: 1, 2, 3, 5, 7, 8, 11

INTRODUCTION – THE STAKEHOLDERS

In a software development project undertaken in industry there are a variety of stakeholders. According to Pressman (Pressman et al, 2015) stakeholders can be grouped as follows: "senior managers who define business issues, project/technical managers who organize and control the practitioners, the practitioners who engineer the system, customers who specify the requirements for the software, and end-users who will interact with the delivered system". These groups can be classified at a higher level as those which are found within the development organization and those which are external. A significant challenge for academic institutions when running project based courses is to ensure an appropriate level of commitment of time and resources from external stakeholders. By external stakeholders we refer primarily to external project providers who initially specify the project vision and scope and also the end users of the product. The process and methodology which we describe below have met the challenge of involving stakeholders and in such a way that the software development process utilized by the students reflects the processes used and favored by industry, namely iterative, lean user experience design and agile software development.

In the context of the courses described in this paper the product is a mobile application and unless otherwise stated, the term stakeholders refers to the external providers of the mobile applications' vision and scope. The stakeholders who provide the projects and are involved throughout the entire development process are wide and varied in terms of the problem domains they represent and also experience in project participation. Initially, there are also widely varying expectations amongst stakeholders towards the finished project and their involvement. Establishing common expectations for stakeholders and project groups is a very important initial activity.

METHODOLOGY

Both the theoretical and practical knowledge required for the projects is provided by two courses: a course in user experience and mobile application development (DTU course 62550) and a course in modelling and software development processes (DTU course 02368). The user experience and mobile application development course provides a thorough foundation in how the desired user experience is achieved and follows a lean UX process with extensive prototyping involving stakeholders in each iteration. Implementation is done in the Android environment. The second course focuses on requirements gathering, software development processes and issue tracking using industry standard software.

At the very beginning of the semester, a seminar is held where the external stakeholders present their project ideas to all the participating students. The students subsequently form project groups themselves based upon their choice of project and start working on the project. Throughout the project period, close collaboration with stakeholders is achieved through a lean UX process with prototypes and a scrum process which delivers increments of the final product in sprints.

We have developed and refined a roadmap which enables 2nd year B.Eng. students to experience "the full CDIO framework" involving external stakeholders:

1. Before the semester start, a call for external project providers / stakeholders is made.
2. At the semester start, the selected stakeholders pitch their projects.
3. Within the following week, the students form project groups.
4. During the remaining semester, an iterative process in close collaboration with the stakeholders is followed.

At the end of the 13 week semester, the students work fulltime on completing the project during a 3 week sprint period.

The individual projects are undertaken in groups with typically five students in each project group. In order to prevent the stakeholders from being overburdened and thereby unable to provide the required level of involvement, usually only one or two student groups is assigned to each project providing stakeholder. Typically, there are around fifteen to twenty stakeholders and a corresponding number of different projects each year. The task of finding project providers has been successfully addressed by project pitching seminars which are held during the second week of term.

PROJECT PITCHING SEMINAR

A project pitching seminar is held where companies and individuals are invited to the university to present their ideas for their mobile application projects to the students on the course and the associated staff. Two project pitching seminars are arranged during the second week of term with different projects being presented at each seminar. Two seminars are held in order to obtain a sufficiently large number of projects such that each project has a maximum of two student groups. It is also a goal that each project presented is chosen by at least one group.

Two to three weeks before the start of the course, advertisements for and invitations to the project pitching seminars are sent out. The project pitching seminar is advertised via numerous channels such as professional groups and networks to a wide range including entrepreneurs and professionals from public and private enterprises. Included in the invitation is a clear description of what is expected from the stakeholders. This includes:

Meeting with the students, physically or virtually at least every three weeks, replying to mails within two working days, providing/discussing project requirements and providing constructive criticism after each iteration and delivery.

The project ideas of companies and individuals who express an interest in presenting at the seminars are assessed and evaluated and those deemed suitable in terms of scope and technical level are selected for presentation. Each stakeholder is given ten minutes to present their ideas followed by five minutes of questions from the audience. After the last presentation, an informal discussion and networking takes place between all participants.

The entire seminar typically lasts for approximately two hours. Photographs taken during the pitching seminars can be seen in Figure 1 and Figure 2 below.

Figure 1. Stakeholder presentation sessions

Figure 2. Stakeholder - student networking

The students then use the next week to form project groups themselves according to which projects they find the most interesting. By choosing their own project from those available, the students are more motivated. When also combined with a stakeholder who is very enthusiastic about their project, it provides an ideal starting point for the subsequent process.

The majority of stakeholders can often be characterized as being very enthusiastic and passionate about their ideas but generally lacking in technical expertise. This is not considered to be a disadvantage as it reflects the conditions often occurring in developer-customer relations in industry. Occasionally, stakeholders are very technically knowledgeable but do not have the time to undertake the project themselves. Examples of previous projects undertaken have included mobile apps for: reading training, Parkinson's disease patients, weather data for agriculture, patients in respirators, educational games etc. Despite many differing problem domains, the learning outcomes are common and aligned with institutional vision and mission (CDIO Standard 3) of DTU. The mission of DTU today is the same as when founded by Hans Christen Ørsted in 1829, namely “creating value for the benefit of society”.

ITERATIONS AND DELIVERABLES

The objective of the User Experience and Mobile Application Development course is to enable the students to identify user needs, conceptualize and validate prototype interfaces based on a lean customer-driven agile iterative design process and subsequently implement the design on a mobile device. As such the course includes of a series of lectures about user experience, interaction design and user interface design. The prototype designs are implemented on the Android platform and a series of lecturers and exercises are given to support this.

A lean process is followed in order to establish the desired user experience. The build - measure - learn cycle is iterated over and over again, validating or invalidating hypotheses, as shown in Figure 3. In some projects, a design thinking process is adopted, following the empathize - define - ideate - prototype - test cycle. For example, the design thinking approach was chosen by a group of students who chose to design and implement an application for type 2 diabetes patients. In the empathize stage, the students themselves established contact to newly diagnosed diabetes patients in the local area, attending meetings in patient organizations and conducting interviews and embodying the “get out of the building” philosophy. Stakeholders representing the end users were thus identified and were subsequently involved for the duration of the entire remaining development process. Having developed an understanding of the users’ problems and needs, prototypes were developed and user research conducted involving the stakeholders. The design thinking approach actively engages the students directly in thinking and problem-solving activities as outlined by CDIO standard 8 (Active Learning). Similarly, the problem domain and close involvement of the end-user requires the students reflect upon their social responsibility as well as the technical analysis and design (CDIO standard 7, Integrated Learning Experiences).

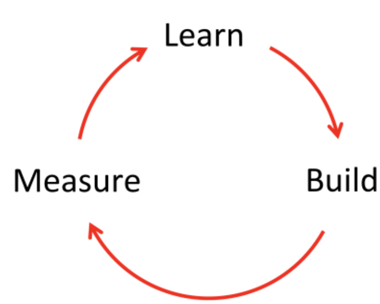

Figure 3. Lean UX Cycle

At the end of each iteration the student groups delivered a series of artefacts to the external stakeholders for review. The feedback and comments received from these meetings were subsequently incorporated in the following iteration. The artefacts delivered to the stakeholders varied as the project progressed from low fidelity wireframes, to high fidelity prototypes and ultimately versioned Android apps, thereby reflecting the CDIO progression. This range of engineering activities is central to the process of developing new products as defined in CDIO standard 5 (Design-Implement Experiences).

Professional tools have been used throughout, with Justinmind (https://www.justinmind.com) being used as the prototyping tool. Using such tools is essential when conducting user research by involving the stakeholders. An overview of the iterations can be seen in Figure 4.

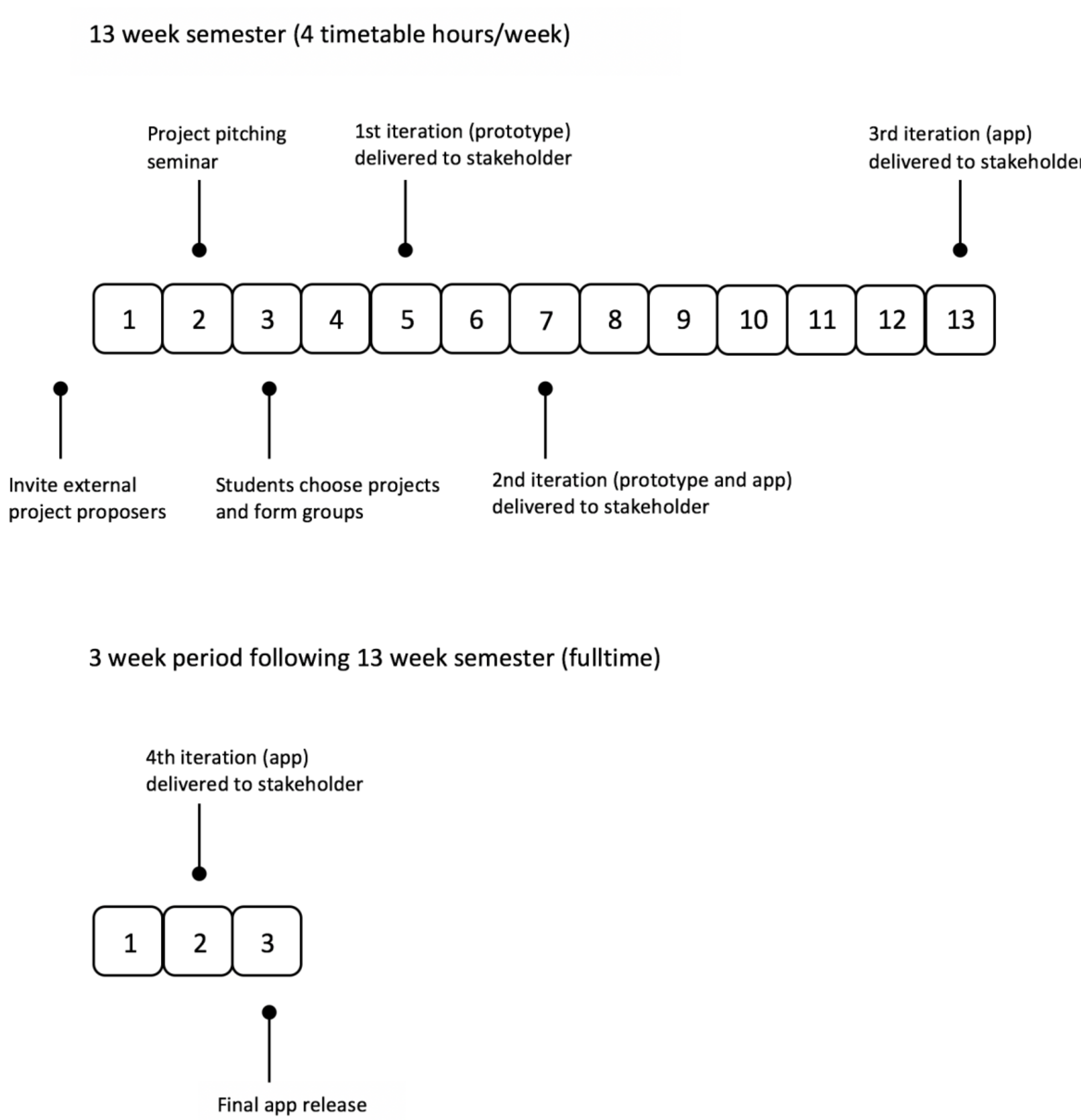

Figure 4. Iteration plan

THE SOFTWARE DEVELOPMENT PROCESS

The development process was supported by a course in software development processes. This implements CDIO Standard 3 (Integrated Curriculum) with the mutually supporting courses having explicit connections with related supporting content, learning outcomes and co-curricular activities.

An agile approach using Scrum was chosen as the overall organizational method combined with selected techniques from Extreme programming (Andrew Stellman et al., 2014). Initially, the students divided themselves into teams of approximately five to six persons, according on the mobile app they chose to work on.

User stories and product backlog

The work begins with each group establishing a preferred method of communication with their stakeholders. In most cases, emails or a digital workspace like Slack (https://slack.com) combined with physical meetings were chosen.

The product requirements were identified through conversations with stakeholders and described by user stories, which are easily understood and provide a value to the stakeholder. Together they form the product backlog.

Prioritizing the Product backlog

After user stories have been identified and added to the product backlog, teams together with stakeholders spend time on prioritizing items. The team assigned story points to each user story, using relative estimation techniques. Since both the domain and the technology were new to most of the teams this was a challenging task. Most teams started allocating a story point value to a simple user story, e.g. login and then estimating the other stories relative to this value. This provided an initial guess of the complexity of each story.

The value of each user story was discussed with the stakeholder. A value point system was agreed on and for each user story, the BFTB ("bang for the buck") ratio was calculated by dividing the value point by the story point.

Releases and sprints

The BFTB values were used in the planning of releases and sprints. Most teams decided to work on one release in the autumn period and one release in the following 3-week period in January. The first release contained the basic functionality of the app and the development phase was divided into two to three sprints of approximately four weeks.

Each user story was broken down into tasks that were developed using selected techniques from Extreme programming. The most common techniques used were: simple design, refactoring and collective ownership, pair programming and test driven development.

A scrum master was appointed who was responsible for setting up daily meetings in the team and setting up the review meeting with stakeholders upon completion of a sprint.

Tool

It was decided that all teams should use the issue tracking tool, Axosoft (https://www.axosoft.com), to control and monitor the development process.

Each user story is entered along with the break down in tasks. As time goes by work effort is registered for each team member.

Axosoft offers a number of valuable visualization tools, e.g. scrum board and a number of gadgets e.g. the burn-down chart for measuring progress, which provide the team with a good overview of the process (see Figure 5 and 6).

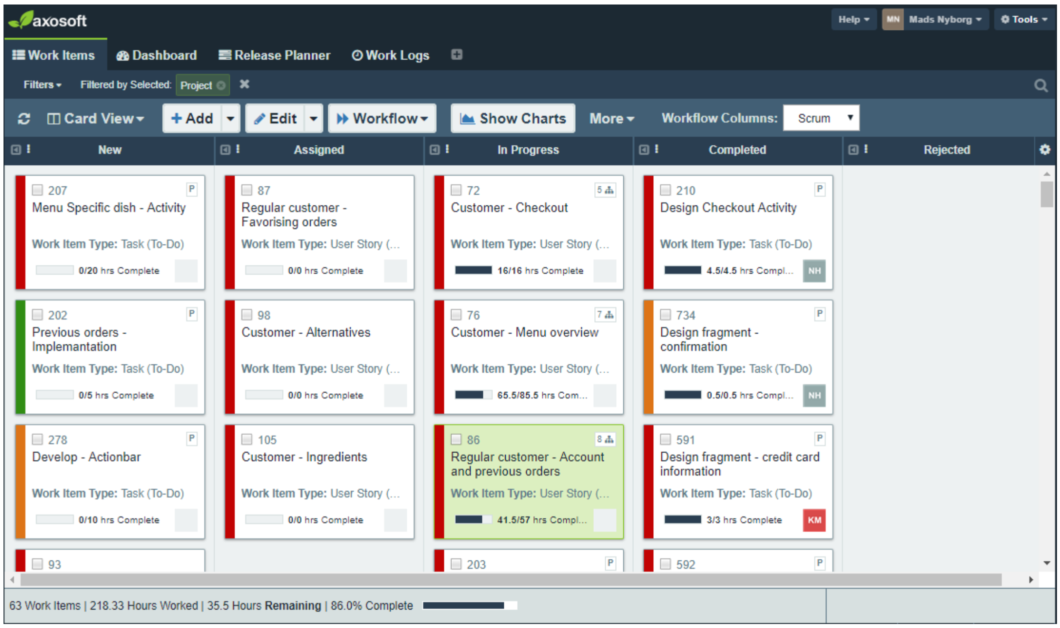

Figure 5. Scrum board for team 23, developing the app:
“The digital restaurant experience” for a Sushi restaurant chain
The task can be dragged and dropped into different states, e.g., New, Approved, In progress, Ready for testing, Completed or Rejected

Figure 6. Dashboard for team 13, developing an app where voting citizens can vote on the parliament's bill. The dashboard shows assigned task for the team and individual members together with the burn-down chart

All teams including their members are set up at course start by the responsible course staff member and hence it is possible to get and overview of e.g. the velocity of all teams.

LEARNING ASSESSMENT

Learning assessment is done both formally and informally using a variety of methods during and at the end of the semester (CDIO standard 11, Learning Assessment). When using an iterative development process in a learning environment, the students are able to compare the artefacts produced at the end of each iteration with previous ones to reflect on the progress in their learning. Quizzes undertaken in a relaxed environment using e.g. a Kahoot quiz (DTU UX Design Kahoot Quiz, 2017) are used as informal status checks. Formal peer reviews are also held along with compulsory assignments which contribute to the final grade are given. At the end of the entire period a final report and poster are delivered. An example of a poster is shown in Figure 7.

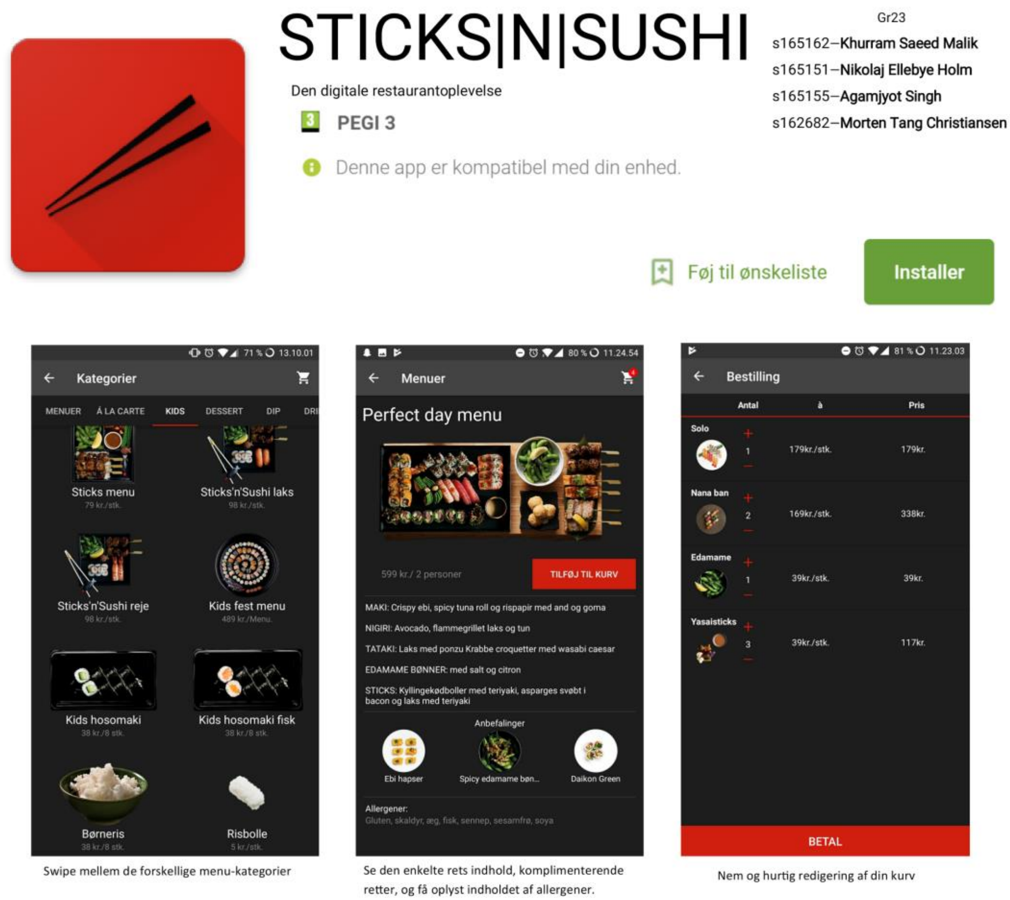

Figure 7. Poster showing the final app for team 23

CONCLUSION AND FINAL REMARKS

A procedure has been described which facilitates the involvement of external stakeholders in project based courses which are compulsory courses in the B.Eng. Software Technology (SWT) and B.Eng. IT and Economics (ITOE) degrees. The involvement of external stakeholders is in fact an essential part of the lean UX process and agile software development process that has been used in the courses. From a CDIO perspective, involving project customers and end users provides the inputs and dimensions required to implement the CDIO standards referred to a greater extent than would otherwise be possible.

The roadmap used to involve external stakeholders is not without challenges though. It requires a good deal of effort to recruit a large number of suitable project providers and who are also able to provide the continuing involvement and commitment required. Aligning expectations and obligations between external stakeholders and the project groups is a task which is essential for the successful involvement of stakeholders and one which must be addressed by the academic staff responsible for the course right from the beginning.

Throughout the course, not unrealistic problems are experienced by groups such as stakeholders failing to provide material and system interfaces, delayed correspondence etc. While the students find this frustrating, the advantages far outweigh the disadvantages. The anonymous evaluations completed by the students at the end of each semester, consistently mention the external stakeholder involvement as a very motivating and rewarding experience.

The following comment was made by a student in the anonymous, end of course online survey:

"*I think this course is exceptionally good because you get the opportunity to work with a real customer. The project pitching seminar is an excellent initiative and works excellently. It is really good to be allowed to make a project that is so close to the real world."*

The benefits for external stakeholders is expressed by the following comment from project proposer Mie Haraldsted from the company rarebird.design:

"Joining the students on a journey to produce a useful app has proved very beneficial for us as a company. The motivation to produce something that we would be pleased about and would use has pushed through a series of questions that has forced us to re-evaluate decisions and correct product specifications. Specifically going through the user journey has created a lot of value thinking of when and in which scenario the app would be used. The students have shared our company vision and have managed to graphically show this to make it a significant part of the product offering. Working with more groups leads to different ways of solving the same issues as well as alternative user interfaces. This will prove very tremendously useful for user testing in the field and propel us forward faster than expected."

Furthermore the project serves as a preparation for the compulsory course "Innovation Pilot" on the 5th semester. In this course, students are also working on project based on wishes from external stakeholders, but without supporting courses (Nyborg et. al. 2016).

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BIOGRAPHICAL INFORMATION

Jacob Nordfalk is an Associate Professor in software engineering at DTU Center for Bachelor of Engineering Studies and freelance consultant. He has extensive industrial experience in software engineering, mobile application development and the teaching of these subjects.
Technical University of Denmark
DTU Center for Bachelor of Engineering Studies - Department of Informatics
Lautrupvang 15
DK-2750 Ballerup
jacno@dtu.dk

Ian Bridgwood is an Associate Professor in software engineering at DTU Center for Bachelor of Engineering Studies. He has several years of experience in software development and in teaching software engineering, mobile application development and user experience.
Technical University of Denmark
DTU Center for Bachelor of Engineering Studies - Department of Informatics
Lautrupvang 15
DK-2750 Ballerup
iabr@dtu.dk

Mads Nyborg is an Associate Professor in software engineering at DTU Compute. He has several years of experience in teaching software engineering and has governed industrial projects both as a consultant on innovative projects and as a supervisor for student projects. He was the one of the primary movers in introducing the CDIO concept at the diploma programs at DTU Compute.

Corresponding author

Mads Nyborg
Associate Professor
DTU Compute
Matematiktorvet
Building 303B
DK 2800 Lyngby
phone: +45 45 25 52 80
mobile: +45 22 17 31 58
manyb@dtu.dk

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BOOK-APP AS COURSE LITERATURE IN CDIO-BASED PROJECT COURSES-STUDENTS' PERSPECTIVES

Erik Hulthén, Panagiota Papadopoulou

Chalmers University of Technology, Sweden

ABSTRACT

Course literature should aim to provide relevant information regarding the fulfillment of course objectives and be adjacent to students' needs and preferences. The course literature in the "Integrated Design and Manufacturing" (PPU175) course at Chalmers University of Technology consisted of a printed book, which was used as a guide to projects' implementation. However, the high price and low transferability of the book pinpointed the need of an alternative option. The solution was a book-app created by digitizing and adjusting the content of the existing book.

This paper follows the development of the book-app and it examines its applicability as course literature in a CDIO-based project course considering students' perspectives and preferences. The first version of the book-app was similar to a PDF whereas the second was enhanced with navigational features. Students' attitudes towards the use of the book-app instead of a printed book as well as their opinions and suggestions about content formulation and app's features were collected after completion of the course through a dedicated survey and a focus group interview.

The outcomes supported that although students were positively predisposed regarding the use of a book-app as course literature, they were not satisfied with the first version of the book-app due to its delayed response and low navigation capabilities. Regarding the second version, they were satisfied with its content and depth of the explanations but they encountered compatibility and navigational issues which affected their overall opinion. The paper concludes that students are ready to use a book-app as their course literature and it suggests design and content features that will enhance the usability and students' satisfaction with the book-app.

KEYWORDS

Book-app, eBook, Digital literature, Project-based learning, Standards: 5, 7, 8

INTRODUCTION

Course literature should fulfill students' needs and preferences in terms of content, format and affordability. Content should be relevant and sufficient to address course objectives and its format should be versatile to different learning styles. Affordability is important to ensure accessibility to course literature to all students. The "Integrated Design and Manufacturing" (PPU175) course at Chalmers University of Technology is a project-based course that aims at giving students a deeper insight and experience of modern industrial methods and methods of product development. The course emphasizes three parallel processes, the development of the technical system, the project itself (project management, economics etc.) and the relations between the members of the group. The provided literature assisted projects' implementation and it consisted of a comprehensive bulky book complemented by lecture notes. The book's price was 1200 kr (+VAT) but for many years it was distributed to students at a lower price (550 kr). However, when this was no longer possible, a need for a more efficient solution in terms of transferability and cost was created.

The high ownership of electronic devices by students and their use during studying (Chen & Denoyelles, 2013) led to the decision of digitizing the book as a solution, considering that electronic books have been found equally effective to printed books for learning (Rockinson-Szapkiw, Courduff, Carter, & Bennett, 2013) while they combine lower cost and weight compared to their printed versions (Dobler, 2015). The latter is substantial, especially for a project-based course where team members have regular meetings in different locations and a bulky book would not be convenient. The digitized content of the book was available to students in an app format for two consecutive years. Due to the app's resemblance with the printed book the term book-app was used. The book-app for this course had two different versions. The first version exhibited slow response while scrolling and included only basic navigation which caused students' dissatisfaction. Muir and Hawes (2013) described slow response and navigation difficulties also as the main issues students encountered while using electronic books. Therefore, the next step was to enhance the first version by incorporating more navigational features and have it evaluated by students. In literature, studies focus mainly on electronic books that are a digitized version of the printed one or to applications that include limited text and act as supplement to course literature (Ling, Harnish, & Shehab, 2014; Teri et al., 2014). Therefore, students' perspectives for the book-app should be gathered to evaluate its applicability as course literature and describe the characteristics it should include.

This paper aims at answering the following questions:

- Is it appropriate to use book-app as literature in a CDIO-based project course from students' perspective?
- What are the main points in the development and usage of book- apps, as literature in a CDIO-based project course, from students' perspective?

METHOD

Book-app description

The development of the book-app was a low-budget university production aiming at providing students with affordable digital literature suitable for project-based courses where easy and immediate access and exchange of information among team members is needed. The book-app was compatible with both Android and iOS operating systems and students could download it through Google Play or Apple Store with 200 kr cost. It was optimized for use in a tablet device while it was possible to be used also in laptops through emulators. Its content occurred from the digitization of the printed book by selecting the relevant parts for projects' fulfillment. Regarding the navigational possibilities the first version included only basic navigation which did not satisfy students whereas the second included more navigational features and connection to external apps to enhance communication and collaboration between team members, characteristics that were also found to be useful based on students' perceptions (Henderson, Selwyn, & Aston, 2017). The current study focuses on students' responses to the second version of the book-app. Figure 1 エラー! 参照元が見つかりません。 depicts the structure of the book-app.

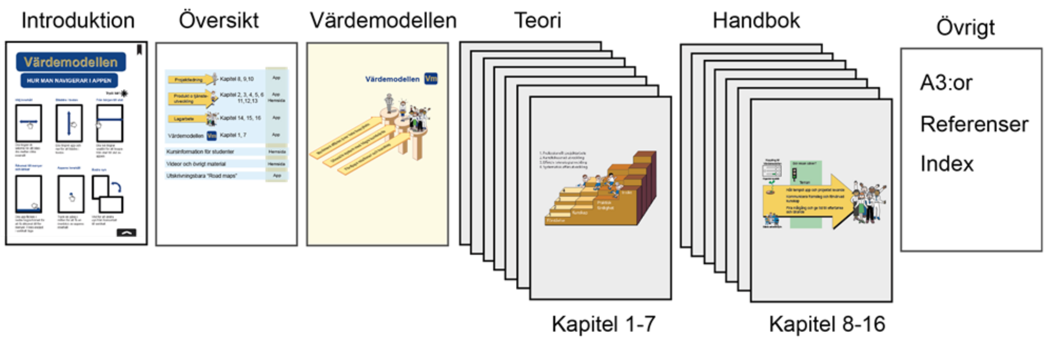


Figure 1. Book-app structure: Introduction with navigation instructions, overview with hyperlinks, content division to theory and project manual, appendix with references and index.

Data collection

The applicability of a book-app as a course literature in a CDIO-based project course was investigated through a dedicated survey and a focus group interview. The dedicated survey included a questionnaire with six closed-ended questions, five of which had a Likert scale response and one with a yes/no answer, and one open-ended end question. The aim was to investigate students' predisposal towards the book-app, their preference between the traditional book and its book-app version, their opinion about the content of the book-app and their overall impression.

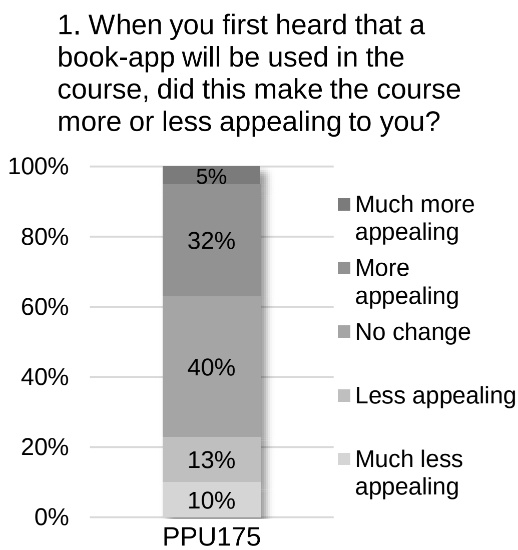
The focus group interview covered the same topics as the dedicated survey with the addition of how the different groups used the provided literature. Four participants were included in the group, the interviewer, a project assistant involved in the course, and three students. The students were from three different project groups to capture a broader behavior. Four open questions were formulated and asked by the interviewer to stimulate the discussion among all participants. A summary of the student's response in each question is presented in the results section. The focus group interview was chosen as a complementary method to give an insight of students' thoughts through question-driven discussion. Both the dedicated survey and the focus group interview were conducted at the end of the course so that students could have highest exposure to the book-app and provide accurate responses.

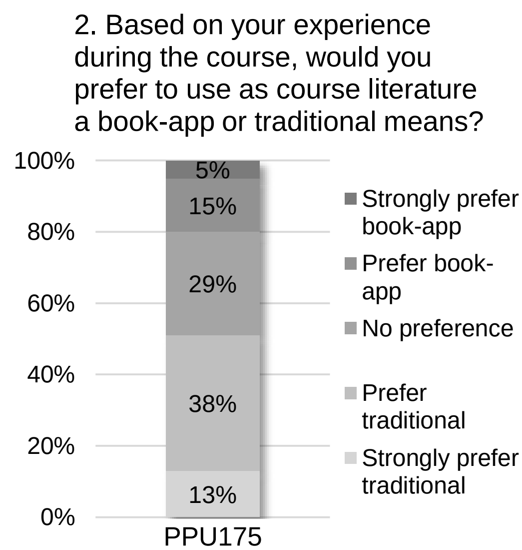
RESULTS

Dedicated survey

In the dedicated survey 89 students responded to the closed-ended questions and 54 of them answered to the open-ended. The results are depicted in Figure 2 and Table 1, respectively. Figure 2.1 and Figure 2.2 aim to depict the thoughts of the students regarding the book-app before the course's start and after its completion, regardless if they bought the book-app or not while Figure 2.3 shows the percentage of students who actually bought the book-app. More specifically, Figure 2.1 depicts the students predisposal regarding the use of a book-app as a course literature. Although 37% of the students thought the course would become at least more appealing, 40% felt no difference. Figure 2.2 presents students' attitude towards the use of the book-app after the course had finished. It can be noticed that the percentage of the students who would prefer the book-app instead of the traditional book dropped significantly to 20% and half of the students (51%) declared to prefer or strongly prefer traditional means as course literature. Figure 2.3 shows that 40% of the students bought the book-app.

Figure 2.4 and Figure 2.5 try to identify how students perceived the educational usefulness of the book-app while Figure 2.6 captures their overall impression about the book-app. Those three graphs have two columns. The first shows the responses of all the students in the survey and the second depicts the responses of the students who used the book-app. In particular, Figure 2.4 shows that from students who used the book-app more than half (57%) believed that the length of the chapters was good while on third of them thought it was little too long. Figure 2.5 shows that almost half of the students (45%) who used the book-app perceived that the depth of explanations provided was good whereas 37% of them declared that the explanations were little too superficial. Figure 2.6 depicts the students' overall impression of the book-app. Half of the students (55%) considered that the book-app was bad or very bad and the rest thought it was either indifferent or good. In all three graphs, the number of students who declared "did not have/use the app" is different than the number of students who did not buy the book-app (Figure 2.3). This shows that a percentage of the students who did not buy the book-app, used or at least tried it from another student. In addition, the question regarding students' overall impression had an even lower percentage of no users compared to the other two questions suggesting potentially that some of the respondents formed their opinion from other students and replied to the question based on that.





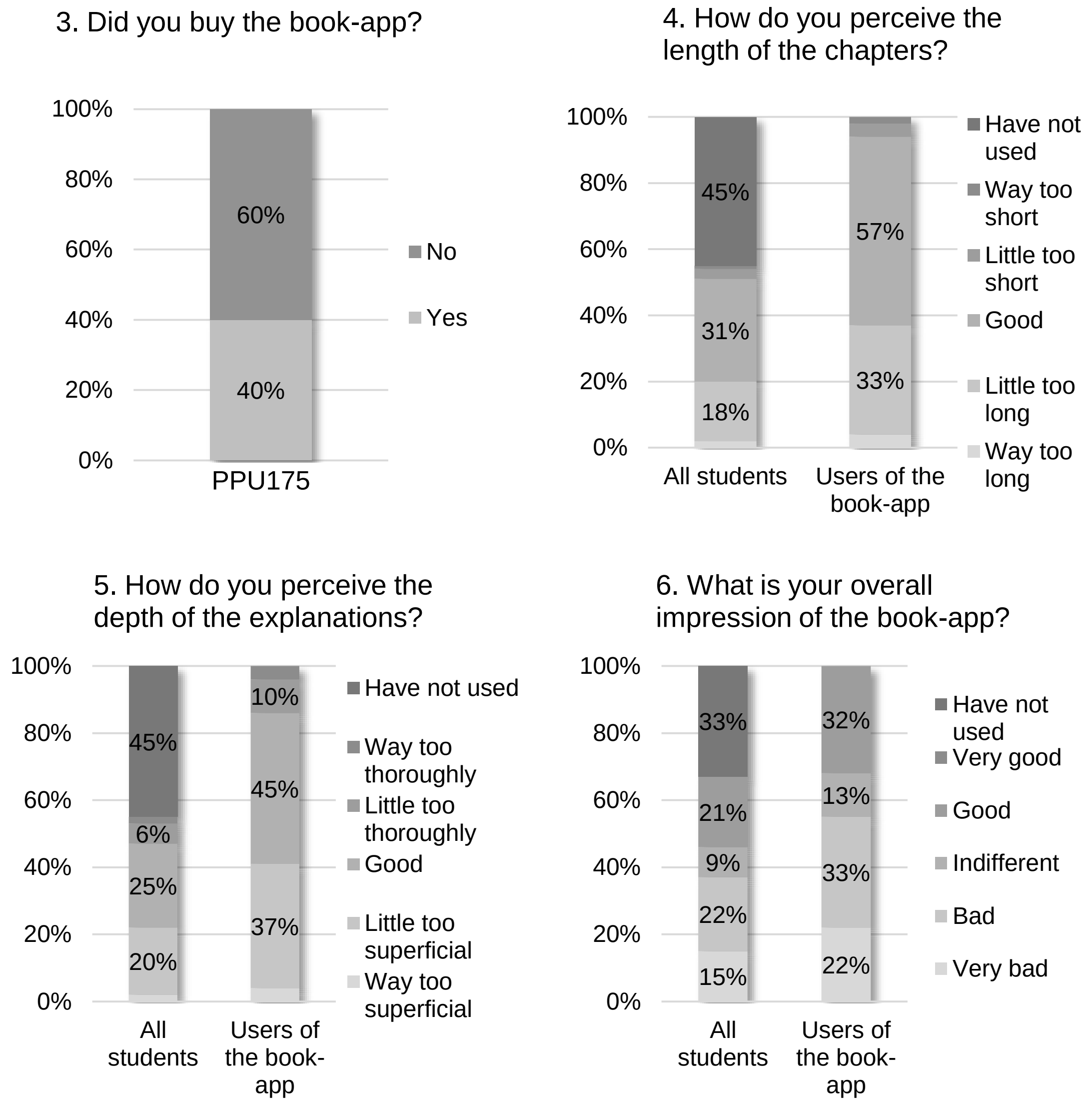


Figure 2. Students' perceptions of the book-app.

Figure 3 presents the correlation between students' opinion about the book-app before and after the course, combined to whether they bought the book-app or not. Students who initially thought that the course was less or much less appealing with the use of the book-app, after the course's completion, they declared to prefer traditional means as course literature with a small part of those who said that the course became less appealing, having no preference. Most of the students who supported that the book-app made no change to the course appealing, they would prefer to use traditional means of literature with one fifth of them having declared that they would prefer the book-app and one fifth having no preference. The students who said the course became more appealing with the book-app, almost half of them showed no preference to the literature means after the course and one fourth preferred or strongly preferred traditional means. The buying behaviour of the students was well distributed regardless of how appealing or not the course became to them.

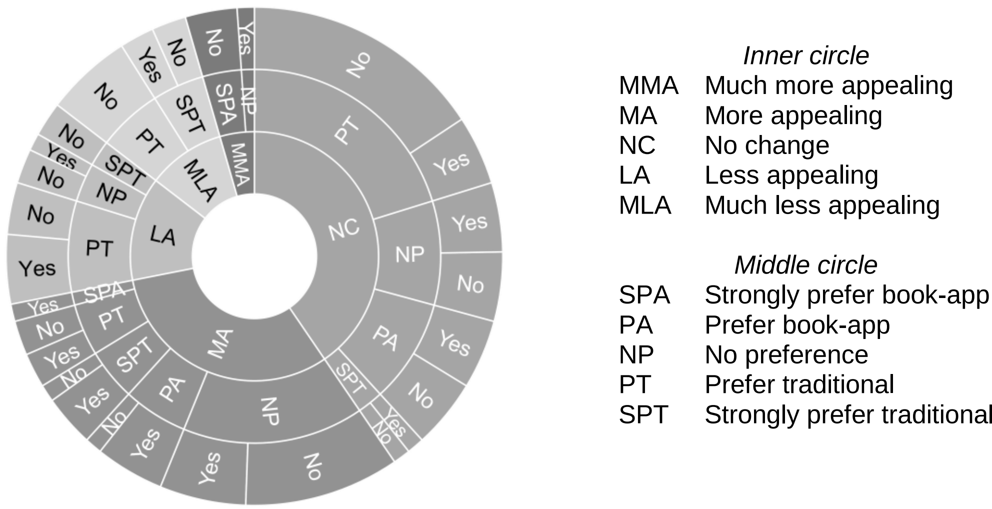


Figure 3. Correlation between students' predisposal towards the book-app (question 1), what they prefer as course literature, (question 2), and whether they bought the book-app or not (question 3). The abbreviations inside the circles are presented on the right part of the figure.

Figure 4 refers to the students who bought the book-app and shows the correlation between the students' perceived length of the book-app chapters and their perceived depth of the explanations. More than half of the students supported that the length of the chapters was good and half of them considered also the depth of the explanations good. However, one third of them thought that the depth of explanations was little too superficial. Additionally, one third of the students who used the book-app said that the length of chapters was little too long and most of those supported that the depth of explanations was either good or little too superficial.

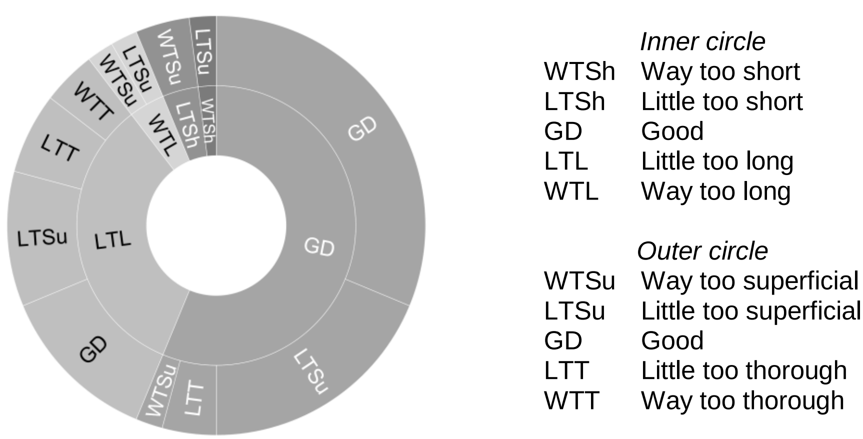


Figure 4. Correlation between students' response regarding the length of the book-app chapters (question 4) and their opinion about the depth of explanations (question 5).

The open-ended question investigated what was missing from the book-app to be featured as a course literature according to students. Students referred mainly to the negative aspects of the book-app. However also few of them took the chance to state that they liked the transferability the book-app offered them and that they advocated the use of an improved book-app. Students' responses were grouped in the six categories of Table 1. Most of the students (70%) mentioned as the most important characteristic missing from the book-app, the compatibility with other devices besides tablet. They wanted the book-app to be compatible with mobile phones and computers without the use of additional software. Another problem one third of the students encountered was hard navigation inside the book-app. Their main comments were: "scrolling and moving between intercepts and chapters were messy", "the activity plan was not properly linked to the rest of the app and very difficult to navigate", "there was no good search function", "a better way to navigate inside the chapter". A few of the students (17%) also mentioned that the user interface was not friendly: "it jumped between pages strangely and it was poorly structured", and they made suggestions for improvements: "remove all surrounding tabs", "a search function would be nice", "a list of contents that you can click on", "bookmarks would be very useful", "if you follow a hyperlink, it would be good to be able to back to where you were before". The cost of the book-app appeared not to be an issue for most of students.

Table 1. Free Text Answers regarding what is missing from the book-app (Number of students that replied N=54).

Negative Aspects:	*% of N*
Lack of Compatibility	70
Hard Navigation	35
Not Friendly User Interface	17
High Price	7

Focus Group Interview

The Focus Group interview consisted of the following four main questions with the students' thoughts pointed out during the discussion with the interviewer being summarized underneath.

1. When you first heard that the course should use a book-app, did that make the course more or less appealing to you?

Students were positively predisposed to use digital literature during the course due to its easier transfer compared to the bulky book. They had a general good impression for the book-app but it was shaded by the fact that it would be available and optimized only for tablets, and it could be used on other devices through emulators, which were not very efficient. They considered it as problem because not all the students possessed a tablet device.

2. How much did you use in your group; book, book-app, lecture slides, other or nothing. How did you use the provided material?

Students referred that their groups used all the different forms of literature that they were provided, the lecture notes, the book and the book-app. The group that had a tablet device with a functioning book-app, used the book-app throughout the course and the lecture notes when something was not included in the book-app. The group that did not have a tablet tried to use the book-app in the computer but it was not compatible so they bought the book and used it for the rest of the course in combination with the lecture notes and sometimes the book-app. The group that owned a book, they used it in the whole course along with the lecture notes and they also tried a little bit the book-app.

3. How do you think was the length of the chapters and the depth of explanations in the book-app? If you have used both the book and the book-app, maybe you can compare them?

Students claimed that all groups were reading only the parts that were suggested by the lecturer's instructions both in the book-app and in the book. If something was unclear or was not included in the app, they referred to the book for a more detailed explanation. Generally, they liked the concise formulation of the app and the extended descriptions of the book.

4. What are the benefits and drawbacks with the use of a book-app as course literature in your opinion?

They believed that the asset of this specific book-app as course literature was the effortless transferability compared to the bulky book and the easier and quicker reference to specific chapters. They agreed that the content and the length of the text were concise and sufficient respectively, and they liked the layout. They were in favor of the book-app prospect and they believed that the price was fair for the corresponding extension of the course, but they would prefer a less complicated interface. They argued that if it had been distributed at a lower price or for free more students would have tried it. The basic problem that they encountered while using the book-app, was that most of the students did not owned a tablet device and they tried to use the book-app on the laptop, where the app was not fully compatible, causing some navigation and functionality problems. Their suggestion for improving the book-app was to add supplementary navigation features such as a search function, a "return to the previous page" ability and a top page button, while they would remove the moving box texts which hindered the scrolling process and some unnecessary according to them bars like the chapter's length.

General characteristics that they considered useful in a book-app was the ability that more than one person could see the same part of the document simultaneously and they could highlight text and add comments and bookmarks in specific parts of the text. They argued that those characteristics could contribute to their work and help them share their opinions and thoughts instantly which was also supported by Millar and Schrier (2015). In addition, a search function was thought to be quite useful and a substantial advantage in comparison with the book, while easy navigation and a simple, friendly user interface would be equally important. Those features could improve team collaboration and project procedures. The students hadn't used a book-app before and were not familiarized, so they had to learn how they could handle it and the complicated navigation procedure did not help them. They think that a PDF-like book would have been easier to read since it is similar to the traditional book.

DISCUSSION

Students were initially positive or neutral to the implementation of the book-app in their course and they acknowledged transferability and low cost as its main advantages compared to the printed book, which was also confirmed by Gueval, Tarnow, and Kumm (2015). However, when course finished, students' intention to use the book-app decreased significantly with only 20% claiming that they would prefer to use it compared to a traditional book. Similar behavior has been identified also in other studies in which traditional books were preferred compared to electronic (Hanho, 2012; Wang & Bai, 2016). The change in the attitude was observed to initially neutral students or those who thought the course became more appealing. Parameters which may affect students' intention to use a book-app can be perceived usefulness of the book-app and students' satisfaction (Joo, Park, & Shin, 2017).

The perceived usefulness of this book-app was investigated through the chapter's length and the depth of explanations for each topic. According to most of the students the length of the chapters was good or little longer from what they would like. The depth of explanations was good or little too superficial. Their approach to literature was to read just the needed information for their task, making the least effort possible. Mizrachi (2015) identified this behavior as a potential parameter for students' choice of reading format.

The satisfaction was examined with students' overall impression and focus group interview. Half of the students who tried the book-app claimed that it was bad. Their main issue was the compatibility with other devices, while many of the students also found the navigation system complicated and wanted a simpler form. Similar issues can be found in literature (Lam, Lam, Lam, & McNaught, 2008). During the focus group interview, students made suggestions on how to improve the book-app by adding features that would assist group-work and learning. Their preferences were aligned with the findings of Chong, Lim, and Ling (2009), who pinpointed students' preferences in eBook's page layout, navigation and content design. The results of this study are limited by the small number of students involved. They refer only to students' perceptions and therefore they do not investigate the impact of the book-app at students' learning.

CONCLUSION

This paper examined the applicability of a book-app as course literature in a CDIO-based project course. The results showed that although students considered initially that the use of the book-app made the course equally or more appealing, after the course's completion most of the them declared to prefer traditional means of literature and had a bad overall impression about the book-app. Students believed that the book-app should be compatible to all devices, since few of them owned a tablet device, have simple navigation and friendly user interface with features that enhance searchability and marking. They think the book-app would be useful during group projects to share information between members and that its content should be concise and provide the needed information for their assignments. There are indications that book-apps can be suitable for project based courses if they are well-designed and comply to students' preferences. Further investigation needs to be carried out including investigation of students learning results.

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BIOGRAPHICAL INFORMATION

Erik Hulthén is an Associate Professor in Product Development and Director of Masters Programme in Product Development at the Department of Industrial and Materials Science at Chalmers University of Technology

Panagiota Papadopoulou is a Project Assistant at the Department of Industrial and Materials Science at Chalmers University of Technology.

Corresponding author

Erik Hulthén
Department of Industrial and Materials Science
Chalmers University of Technology
Campus Johanneberg, Hörsalsvägen 7A
SE- 41 296. Göteborg, Sweden
+46 31 772 58 54
erik.hulthen@chalmers.se

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BALANCING ONLINE AND FACE-TO-FACE TEACHING AND LEARNING ACTIVITIES

Emiel van Puffelen

4TU.Centre for Engineering Education,
Wageningen University & Research, The Netherlands

Melanie van Berkum, Julia Diederen

Department of Agrotechnology and Food Sciences,
Wageningen University & Research, The Netherlands

ABSTRACT

The core of university course design is the selection and combination of Teaching and Learning Activities (TLAs). TLAs may involve various types of interaction, either face-to-face or with and through media. Traditional media such as books are increasingly being supplemented with many types of online media such as short video presentations known as knowledge clips. Wageningen University introduced knowledge clips to several second-year Food Technology courses, partially shifting from face-to-face interactions to online activities that facilitate acquiring, inquiring and practicing. Student questionnaires and a student group interview were used to reveal differences in student preferences towards knowledge clips and the other TLAs. Knowledge clips seem to be valuable parts of courses and work well in general, although students prefer to combine them with some face-to-face interaction. Besides individual preference, there seem to be two main reasons for this: (1) watching a large number of clips requires a considerable amount of discipline and a face-to-face meeting during the course is an intermediate goal to work towards, and (2) when knowledge clips are more difficult and raise questions, students prefer to work in a room with access to a teacher.

KEYWORDS

Teaching and Learning Activities, Face-to-face, Online, Course design, Knowledge Clips, CDIO standards: 5, 6, 7, 8, 10, 11

INTRODUCTION

Developing university courses usually involves a cycle of designing, building, executing and evaluating. The design phase should be based on a well-constructed curriculum and properly formulated Intended Learning Outcomes. The core of course design consists of the selection and combination of Teaching and Learning Activities (TLAs). Generally, a smart design involving a combination of different types of TLAs is required to create a top-quality university course (van Puffelen, 2017). One option is to develop a course with information-gathering activities for students, devoting class time to discussions, peer interactions, and the assimilation of knowledge (Mazur, 2009). This flipping of the classroom approach requires the provision of media to support students in their information gathering.

The use of traditional media such as books is increasingly being supplemented with several types of online media. These media can be used to restrict face-to-face interactions to situations in which they are really needed, such as activities to follow up on learning achieved using media or activities aimed at higher-level learning outcomes. The result is that online learning becomes a larger part of student learning activities; however, this might not always be without consequences for learning motivation. Christiansen et al. (2017) found that students achieved lower scores on quizzes performed at home compared with in class. Survey feedback showed a strong preference for taking quizzes in class and indications that take-home quizzes demotivated attendance and the pre-class watching of videos. Pfeiffer, Scheiter, and Gemballa (2012) found that students who had prepared for a task using digital videos were less motivated than students who were trained in class, although a combination of both approaches was best.

Massive Open Online Courses (MOOCs) can even be restricted to 100% online TLAs. A literature review (Hew & Cheung, 2014) showed that many MOOCs have a structure equivalent to university courses, using video lectures, examinations and/or individual final projects, as well as online discussions. The main differences found between MOOCs and university courses were that MOOCs had larger and more diverse student enrolment, higher drop-out rates and a relative lack of instructor presence or support. MOOCs also suffer from a lack of student response in the online discussion and, for the teachers, the sense of speaking into a vacuum because of the absence of student immediate feedback. These findings could indicate that learning is less effective with MOOCs due to a lack of face-to-face interaction.

The low completion rates of MOOCs (Hew & Cheung, 2014; Jordan, 2015) might also be partially explained by the selection and intentions of MOOC students. Since most users of MOOCs are not part of a study programme, completing the whole MOOC is not necessary. Still, it is wise to investigate student perception when increasing the use of online activities in university courses, as well as the possible limitations. The student perception might be influenced by the way that online and face-to-face activities are mixed. Figure 1 (based on Laurillard (2012, 2016)) gives an overview of types of learning; acquiring, inquiring, producing, practicing, discussing and collaborating. Courses can contain these types of learning using any combination of online and face-to-face TLAs.

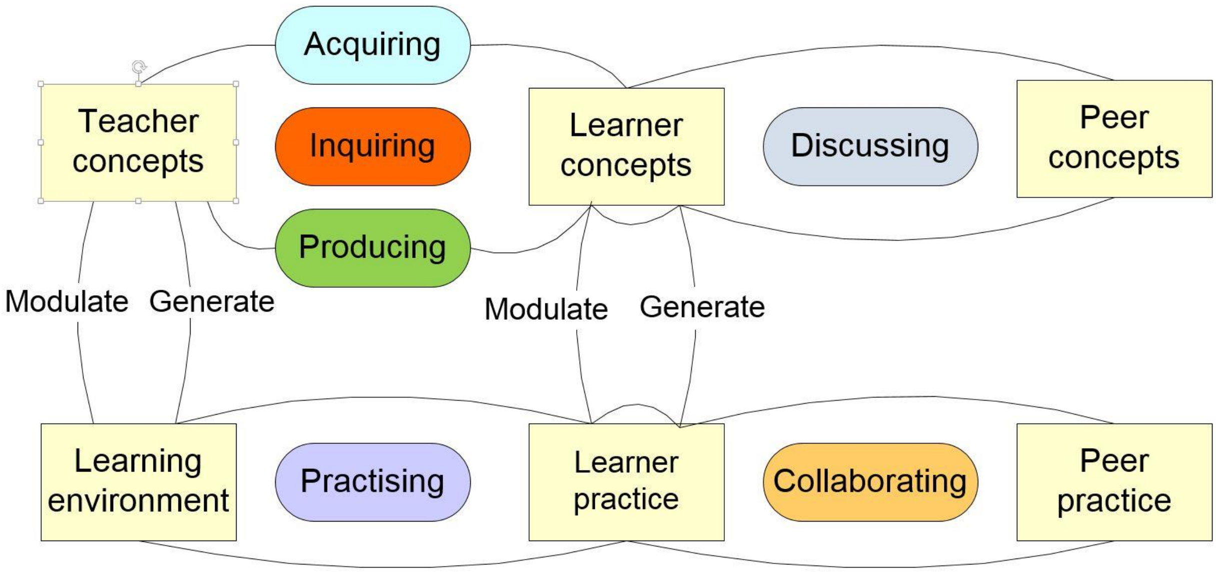

Figure 1. Types of learning targeted by TLAs (based on Laurillard, 2012, 2016)

Acquiring knowledge can be supported online using knowledge clips (short video presentations of a single topic). Long, Logan, and Waugh (2016) found that, for pre-class learning, videos should be combined with other activities to ensure students have learned the knowledge covered in the videos and are prepared for the in-class activities. Fabregat-Sanjuan et al. (2017) successfully used out of class self-assessment in combination with online video clips to achieve this, while Moos and Bonde (2016) found that embedding prompts in the video had a positive effect, causing students to better self-regulate their learning.

Wageningen University has introduced knowledge clips and other online TLAs, such as digital exercises and assignments with built-in feedback, in several second-year food technology courses. The implementation of online TLAs has led to a partial shift from face-to-face to online activities for acquiring, inquiring and practicing activities. The implementation of knowledge clips and other online TLAs in combination with face-to-face TLAs has been evaluated at the course level. This paper focuses on the student perceptions of the resulting TLA combinations used in two second-year bachelor's courses with different TLA combinations: Food Microbiology and Mathematical Concepts for Food Technology.

METHODS

Course guides and evaluations of the courses Food Microbiology (Course 1) and Mathematical Concepts for Food Technology (Course 2) were studied to create an overview of their TLAs. The overview was used to design questionnaires, which were also discussed in detail with the course co-ordinators.

The paper-based questionnaires were provided to the students immediately after the completion of their respective course exams. In these questionnaires, students were asked to indicate the extent to which they agreed or disagreed with statements about the TLAs using a five-point Likert scale, ranging from 'strongly disagree' (1) to 'strongly agree' (5).

Students were also asked about their attendance and the percentage of exercises completed using a five-category scale: 0–20% (1), 20–40% (2), 40–60% (3), 60–80% (4) and 80–100% (5) attendance. Students were asked to participate in a semi-structured group interview one month after the course, during which the questionnaire was discussed in detail.

Course 1 starts with a few introductory lectures and has ~60 knowledge clips (each not more than 10 minutes in length) that replace lectures and offer corresponding digital exercises. Several contact points are scheduled throughout the course, in which students can ask questions. During tutorials, students work on digital assignments with built-in feedback. The tutorials are held in computer rooms, with teachers available to answer questions. Live question hours are scheduled after the tutorials, where the teacher discusses questions about the tutorial that are posted on a digital blog. The pre-lab activities are digital activities held in a scheduled computer room, with teacher available to answer questions and attendance being compulsory. For the pre-lab and lab classes, students are offered about 30 knowledge clips to explain several techniques.

In Course 2, students work on ~30 exercises, each consisting of 10 to 20 calculation questions. Every day, computer rooms are scheduled for the students and several teachers are available to provide help; however, attendance is not compulsory. In addition to the exercises, students work on three digital cases, which are large digital assignments consisting of several interactive questions with built-in feedback, which student need to finish within a scheduled time slot. The course has no lectures but contains several types of knowledge clip: theory clips (introducing a theory in general), introductory clips (introducing the exercise) and wrap-up clips (explaining the answers).
Course 1 was taken by 288 students and Course 2 was taken by 197 students. Both courses were scheduled during the same term, and most students (~160) took both courses simultaneously.

RESULTS

Questionnaires

The questionnaire results for Course 1 are shown in Table 1, with the scores (out of 5) for how valuable students regarded each type of TLA shown in bold. Both the lowest and highest scores were for an in-person TLA; introductory lectures: 2.97 and laboratory classes: 4.21.

The general score for the TLAs was above the neutral score of 3.0, and the differences between them are small (insignificant) compared with their standard deviations (ranging from 0.68 to 1.30).

Table 1. Questionnaire results for Course 1, out of a maximum score of 5. n = 101–122.

TLA questions	Mean	SD
The **introductory lectures** were valuable.	**2.97**	1.25
There was inconvenient overlap between introductory lectures and knowledge clips.	3.40	1.05
What percentage of the introductory lectures did you attend?	3.87	1.33
I am satisfied with the help of the teachers/supervisors during the tutorials.	3.24	1.00
What percentage of the tutorials did you attend?	2.40	1.53
The knowledge clips were a valuable part of the course.	4.14	0.95
What percentage of the knowledge clips did you watch?	4.54	0.94
The exercises (corresponding to the knowledge clips) were valuable.	3.81	0.83
What percentage of the exercises did you make?	4.23	1.07
The **digital assignments** were a valuable part of the course.	**3.79**	0.90
The **pre-lab activities** were a valuable part of the course.	**3.05**	0.98
The pre-lab activities were a good replacement for part of the laboratory classes.	3.16	1.07
The knowledge clips of the pre-lab activities were a valuable part of the course.	3.21	0.96
What percentage of these knowledge clips did you watch?	4.07	1.20
The exercises of the pre-lab activities were valuable.	2.97	1.00
What percentage of these exercises did you make?	4.00	1.33
The **laboratory classes** were a valuable part of the course.	**4.21**	0.68
The **life question hours** were a valuable part of the course. (n = 65)	**3.22**	1.02
What percentage of the life question hours did you attend?	1.83	1.35
I am satisfied that the **knowledge clips** replaced part of the lectures.	**3.38**	1.30
I prefer to have more lectures instead of knowledge clips.	3.37	1.35
I prefer to have more face-to-face contact with teachers/supervisors during course.	3.44	1.15
Questions scale: 'strongly disagree' (1) to 'strongly agree' (5) Attendance / completion scale: 1 = 0–20%, 2 = 20–40%, 3 = 40–60%, 4 = 60–80%, 5 = 80–100%		

The questions for Course 1 were answered by between 101 and 122 students, with the exception of the question on "life question hours", which was answered by just 65 students. This low response rate could be explained by the low attendance score (1.83) for life question hours, although the students that did answer this question appreciated this TLA as much as the others, giving it an above-neutral score (3.22). The attendance scores for the other TLAs were 3.87–4.23, indicating an average attendance of about 60–80%. Again, the standard deviations showed a relatively large variation in the scores.

The tutorials and pre-lab activities both combined digital exercises and knowledge clips. The questions on each of these components had scores similar to those of the main TLAs (all above the neutral score, with small differences relative to the larger standard deviations).

The results for the final three questions could indicate that students do not object to knowledge clips in general, but that for this course the amount face-to-face contact was a bit too low.

The questionnaire results for Course 2 are shown in Table 2. The range of scores for the TLAs are comparable to those of the first course, 2.99–4.01, with most above the neutral score of 3.0. Again, the differences are small (insignificant) compared with the relatively large standard deviations, which range from 0.73 to 1.20.

Table 2. Questionnaire results for Course 2, out of a maximum score of 5. n = 129–149.

TLA questions	Mean	SD
The possibility to work on the exercises during the **exercise classes** (in a computer room with a teacher/supervisor present) was valuable.	**4.01**	0.98
Working with peer groups of 3 persons was a valuable part of the exercise classes.	**3.22**	1.20
What percentage of the exercise classes did you attend?	3.26	1.50
The (digital) **cases** were a valuable part of this course.	**4.01**	0.73
The possibility to work on cases during classes (in a computer room) was valuable.	4.17	0.88
What percentage of the cases did you make in a computer room?	3.78	1.57
The small wrap-up clips of the cases were valuable parts of the cases.	**2.99**	1.04
What percentage of the small wrap-up clips of the cases did you watch?	2.79	1.48
The **introductory clips** were valuable (introducing the exercises).	**3.12**	1.11
What percentage of the introductory clips did you watch?	3.08	1.39
The **theory clips** were valuable (for example, about the Arrhenius equation).	**3.95**	0.85
What percentage of the theory clips did you watch?	3.52	1.35
The clips which explained the answers of the **exercises** were valuable.	**3.34**	1.07
What percentage of the clips which explained answers of exercises did you watch?	2.97	1.33
The pdf documents/slides which explained answers of exercises were valuable.	**3.84**	1.06
What percentage of pdf docs/slides explaining exercise answers did you look at?	3.98	1.17
I appreciate clips more than pdf documents/slides to check my answers.	2.43	1.29
Questions scale: ‘strongly disagree’ (1) to ‘strongly agree’ (5) Attendance / completion scale: 1 = 0–20%, 2 = 20–40%, 3 = 40–60%, 4 = 60–80%, 5 = 80–100%		

The questions for Course 2 were answered by between 129 and 149 students. There were four different types of clips in this course: introductory clips (to introduce exercises), theory clips (to explain theory), wrap-up clips (to wrap-up the case) and screen-recording clips (to explain the answers of the exercises). The mean watch rate for the clips was between 2.79 and 3.52, both above and below the neutral score of 3 (40–60%), and again, there were relatively large standard deviations.

Semi-structured group interview

Five students participated in the interview about the questionnaires, which yielded valuable remarks and explanations of the questionnaire answers for the courses, both individually and in combination.

Knowledge clips

Students indicated that the combination of Courses 1 and 2 was difficult. Both courses had many knowledge clips, which required a lot of discipline to complete. Students were used to the learning activities of courses from the previous year, which did not include the use of knowledge clips. Students stated that they needed more time to get familiar with the knowledge clips and explained: '*We had to watch about 60 knowledge clips. That is quite a lot'*.

For Course 1, a schedule was provided for watching the clips and completing the corresponding exercises. The students appreciated the schedule but found it difficult to follow because it required a lot of discipline. Some students also missed having contact with fellow students and teachers, and therefore made use of available rooms to watch the clips together with other students. Other students appreciated the fact that they were able to watch the knowledge clips from home and were not obliged to visit the campus.

The students watched the knowledge clips but, although it was explained beforehand, did not always know where and how to ask questions about their content. They did not always understand how the knowledge clips related to information provided in the other (online) learning activities.

The appreciation for online TLAs depended on the nature of the course. For the explanation of concepts, knowledge clips were found to be sufficient without any further supervision. In Course 2, where students needed to make difficult calculations, they appreciated the possibility of watching knowledge clips and completing exercises in a room with teachers available. For this type of learning, students would appreciate some whole-class teaching; for example, the explanation of an exercise.

Students do not agree on whether lectures should be replaced with knowledge clips. Some students appreciated the flexibility of knowledge clips and were happy for their contact with teachers to be limited. Other students missed having contact with teachers and fellow students and were in favour of TLAs that take place at the university, with the supervision of teachers.

In general, the knowledge clips were considered a valuable part of the course, but students thought they should be combined with opportunities for teacher interaction.

Student preferences for Courses 1 and 2

Small differences in the attendance rates and evaluations of usefulness of the TLAs between the two courses could be explained by their difficulty levels: students considered the knowledge clips and exercises of Course 1 easier because they largely comprised explanations of concepts. Students did not have many questions related to this and could complete everything online without supervision. The content of Course 2 was considered more difficult because the knowledge clips contained explanations of the calculation exercises and raised more questions; therefore, students preferred to work in a room with supervision. Also for this purpose, most students tended to prefer slides above knowledge clips containing an explanation of the calculation exercises, because this made it easier to follow the calculation. Some students indicated that they did not attend all the tutorials, and preferred to complete (some of) the exercises at home.

In Course 2, there was no whole-classroom teaching; the students were allowed to form groups and solve the exercises together, stimulating interaction. Students did not always find this useful because it took them longer to finish the exercises. Some would have appreciated more whole-classroom teaching, which keeps them more motivated and able to sustain the required pace; however, other students appreciated the fact that the TLAs were digital, enabling them to work from home at their own pace.

DISCUSSION AND CONCLUSIONS

TLA combinations

The questionnaires and interview show that the knowledge clips seem to work well in general. They also show that students prefer to combine knowledge clips with other TLAs. Besides preference, there seem to be two reasons for that: watching a large amount of clips requires a considerable amount of discipline and face-to-face meetings in between sets intermediate goals to work for. Also when knowledge clips are more difficult (e.g. explaining a calculation) and raise questions students prefer to work in a room with supervision.

The large standard deviations show that students differ in preference for all the online and face-to-face TLAs used in the courses. Boelens, De Wever, and Voet (2017) formulated four goals for the design of blended courses: (1) incorporating flexibility, (2) stimulating interaction, (3) facilitating students' learning processes and (4) fostering an affective learning climate. It seems that the two courses reached at least the goals 1 and 3 to some extend as all TLAs were scored as neutral or above despite differences in student preferences towards the various TLA types. This might indicate that the different TLA types offered, enabled most students to find TLA combinations that worked for them.

Implementation

When online TLAs (such as knowledge clips) are introduced, it is important that students receive guidance on how to work with them to reach the learning goals. In that way, students can become familiar with the new TLAs, decide whether a learning activity is useful for them to attend, and understand how to make effective use of it. Study programmes should slowly introduce knowledge clips; a sudden change from courses with only lectures and group work to courses with knowledge clips and digital learning material might confuse students in their learning strategies.

FUTURE WORK

Wageningen University continues to monitor ongoing interventions in the Food Technology courses, and the future comparison of more course types may yield new insights. One option would be to additionally survey whether a course stimulates interactions and foster an affective learning climate. This might be combined with courses containing online and face-to-face TLAs that facilitate discussion and collaboration (right side of figure 1).

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BIOGRAPHICAL INFORMATION

Ir. Emiel A.M. van Puffelen is the leader of the 4TU.Centre for Engineering Education at Wageningen University & Research. At Wageningen University he has supervised the creation and full scale operation of the University Teaching Qualification programme. He also developed MOOC production teams, knowledge clip studios, the education innovation consultancy, the educational portal and the team for the innovation of the IT learning environment. He was previously a senior consultant in the innovation of higher education, working for national organisations, and has a special interest in activating learning, blended learning, training teaching staff and the novel design of curricula and courses.

Melanie van Berkum MSc is an educational developer and teacher in the Food Process Engineering group at Wageningen University & Research. She has a Master's degree in Science Education and Communication.

Dr. Ir. Julia Diederen is a lecturer in the Department of Agrotechnology and Food Sciences at Wageningen University & Research. She has a PhD in designing digital learning materials for food chemistry education, and is currently designing virtual laboratory simulations to foster the acquisition of scientific skills. She is also involved in several education innovation projects.

Corresponding author

Ir. Emiel A.M. van Puffelen
Wageningen University & Research
P.O. Box 9101, 6700 HB Wageningen
The Netherlands
31-317-484568
emiel.vanpuffelen@wur.nl

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BUILDING STEM EDUCATION FRAMEWORK THROUGH NETWORKING COLLABORATION

Aleksandr Arnautov, Natalia Gafurova

Siberian Federal University

Yaroslav Fadeev, Viktor Dyomin

STEM-Games LLC

ABSTRACT

The paper shares the experience of implementation of STEM-based learning in undergraduate programs, organized through networking collaboration between Siberian Federal University and STEM-Games LLC. Proposed gamification model is applied through the first year of Introduction to Engineering course as a stage of students' first acquaintance with the problems of engineering profession. STEM-based learning activities are shaped into two modules representing a team-based engineering design competition with emphasis on different aspects of engineering. The modules utilize the principles of CDIO bringing up project-based approach and active learning as primary educational techniques. The paper address major issues concerning seamless intercurricular integration of STEM-based learning. Finally, the paper shares the most recent results of the institutions' collaboration within CDIO-based programs of SibFU. Significant point is made in students' abilities for self-study and problem solving. Proposed contextual gaming activities put attention to practical importance of natural sciences, being as a starting point for developing students' engineering thinking and learning motivation.

KEYWORDS

STEM, Gamification, Introduction to Engineering, Engineering Thinking, Standards 3, 4, 7, 8

INTRODUCTION

To educate engineers able to successfully perform professional tasks in a rapidly changing world, the education itself should evolve in the very context of engineering problems and challenges the society and technology are facing now (Jeschke, 2016). Worldwide CDIO Initiative propose a practice-oriented approach based on a concept of learning by reproducing a production cycle of engineering design throughout various educational practices and learning activities (Crawley et al., 2007). The CDIO approach requires substantial changes in traditional theory-based education resulting in the shift towards active and project-based learning.

The first challenge of designing CDIO-based curriculum is to overcome historically shaped paradigms and common attitudes concerning education process. The most probable conflict emerges at the point of rethinking the natural sciences – math, physics and chemistry, which are the basis of all technical knowledge. However, as the engineering problems become more complex and interdisciplinary, the body of conceptual knowledge of natural sciences is no more sufficient for an engineer to answer today's challenges (Kamp, 2016). Thus, the traditional theoretical mode of natural sciences is a subject to change for modern engineering education.

Aiming to increase learning effectiveness, education system is shifting from passive knowledge transition towards experiential knowledge acquisition through various learning activities including games (Standard 8). The latter are the form of active learning based on a principle that students acquire experiential knowledge through acting simulated gaming patterns. Games are best known for learning efficiency caused by participants' emotional immersion in the process of reaching game goals and perceiving situations of success (Hamari et al., 2014). Adding gaming principles to non-gaming activity, referred as gamification (Herger, 2014), became a widespread phenomenon in diverse areas including education.

The concept of STEM (Science, Technology, Engineering, Math) was created to answer the needs mentioned: both to improve education quality in natural sciences and update methodological apparatus of these disciplines to the current needs, as well as to bring engineering context in learning process (Gonzalez & Kuenzi, 2012). Combining the conceptual basics of natural sciences and gaming principles, STEM learning aims to bridge theory and practice at high school level and earlier stages of higher engineering education. Despite the criticism of gamification phenomena (Fuchs et al., 2014), certain STEM techniques can be applied within engineering undergraduate programs as a stage of students' acquaintance with engineering professions at the beginning of their studies in university (Standard 4). In general, STEM games put attention to significance of natural sciences and demand for integrative application of their concepts in solving engineering problems.

The main idea of the paper is that applying the concept of STEM learning through the series of introductory modules at the first-year of undergraduate programme could facilitate students' interest in studying natural science and encourage them towards problem-based learning.

A STEM MODULE CONCEPT

STEM-based practices within the current research were initially developed by STEM-Games LLC (formerly affiliation of Moscow Polytechnic University) and implemented in the educational process of Siberian Federal University (SibFU). Continuous collaboration between the institutions resulted in rethinking STEM-based learning and development of the STEM Module, which further expands the basic idea of combining natural sciences, engineering context, and gamification into an immersive learning activity.

The STEM Module is represented by two minor modules, each designed as a team-based engineering design competition for the first-year undergraduate students with emphasis on the certain aspects of engineering. Overall, the STEM Module is aimed to provide semester-long learning activity stressing both basic theoretical and practical knowledge of freshmen students.

“Engineering Cluster”

The STEM Module starts with a STEM game “Engineering Cluster”, which brings the content of natural sciences into gamified digital setting. The game represents an online market simulator, where student teams become competitive companies developing high-tech engineering products. Educational purpose of the “Engineering Cluster” is to utilize the content of physics, chemistry and math at the level of the first year undergraduate programme by using the project-based approach to emphasize engineering and economical context. The game plot suggests that students’ companies must compete at the product market by means of their products quality and business strategy.

The key features of the “Engineering Cluster” game are as follows:

- Digital setting
  The game developed as a website with simple and modern graphical structure, providing necessary commentaries and guides for navigation. Training missions are available for faster acquaintance with game mechanics.
- Content-integrated real-life products
  In-game products are represented by calculation models of real-life engineering products, adopted for the first-year undergraduate programme level. Each product represents a problem within a single topic of natural science discipline – physics, chemistry, or math. Additional products for technical drawing were introduced in the latest version of the game.
- Diversity and interdisciplinarity
  Game products are interdependent and ranged by difficulty: high-level products include several correlated low-level products. Each product has a multitude of potentially correct solutions. High-level product requires solving different problems from different areas in parallel so that students can explicitly see the connection between physics, chemistry and math within a single engineering problem.
- Quality improvement cycle
  The game mechanics simulates Deming’s PDCA cycle representing iterative process of planning-designing-simulating-production for each product (see Appendix A).
- Market economy
  Each team has its own economic potential influenced by the quality and complexity of their products. The teams maintain their own game budget and undertake business transactions with each other at the game market. An auction system is introduced in the latest version of the game providing deeper understanding of common market laws.
- Teamwork
  Considering a multitude of in-game sub-processes, strong teamwork based on effective role management is the only winning strategy.

The “Engineering Cluster” game can be exemplified with a production chain of one of the high-level products – Winged rocket (Figure 1). In order to produce a Winged rocket, the team must obtain its components: Rocket Engine and Accelerometer. The project requires a Rocket Fuel in order to produce the engine.

Each product in the chain refers to a problem within a particular area of natural science:

- Rocket Fuel – combustion heat calculation for selected fuel compound;
- Accelerometer – Hooke’s law application and statistical error analysis;

- Rocket Engine – heat balance calculation for isolated thermal system;
- Winged Rocket – flight trajectory analysis represented by saddle surface.

Figure 1. Winged Rocket production chain

To produce a correct solution for each product, students have to fulfil their theoretical knowledge in the problem area. In contrast with the traditional mode of study, the theoretical input is initiated by students themselves, providing teacher with full ready-to-learn class. Considering real-life context of the tasks, students can explicitly see the connection between natural science and engineering. However, being purely digital, the game lacks hands-on experience, grasping only the theory of natural sciences using STEM learning approach.

"Engineering Start"

The "Engineering Start" game represents real-life design competition where student teams design and assemble various engineering products with specific requirements. Each product's functioning based on a different principle of math, physics, or chemistry, whereas the competition stresses the efficiency of its application to the final product. Generally, the game bridges basic theoretical knowledge of natural sciences with its practical application and facilitates the ground level of engineering design skills using STEM concept.

The key features of the "Engineering Start" game are as follows:

- Hands-on tasks
  The game task is a project of designing a physical model of an engineering product, capable of performing specified function. The competition requires student teams to complete several tasks during the game, resulting in a series of different products (usually 3-5).
- Requirements and limitations
  Each task has a diverse range of solutions; however, the main challenge is to meet technical requirements for each product. In-game limitations (e.g. financial, physical) allow to maintain the range of products' parameters and control requirements violation.
- Production cycle
  The projects are organized in a way which simulates an engineering cycle, including resource planning, designing, building and testing the product. Student teams are required to prepare technical report for each product, including description, drawings, and list of materials.
- Resource management
  Student teams are expected to plan, select and use the materials and tools according to their own project idea. Teams are also allowed to prepare an inquiry for specific materials and tools not presented in the workspace. Using materials not listed in the report is not allowed.
- Workflow
  Student teams use dedicated workspaces to work on their projects supervised by faculty and tutors. The access to the workspaces is time-bound in order to provide equal

opportunity for every team. Each product is required to pass safety check prior to the final completion.

- The Competition
  The final competition is held for all the teams to demonstrate their products on a test site. The best products is selected using the design, test results, safety, and budget criteria.

The main point of the "Engineering Start" game is that students learn how the theoretical principles of natural science apply in real-life products as they build and modify them in order to meet the performance and safety requirements. For example, to design a catapult, students need to acknowledge themselves with the basics of mechanics, such as leverage, momentum, elasticity, and ballistics. Moreover, students can experiment on how these principles behave when they modify the catapult design or use another material while searching for desired performance. The requirements are that the catapult, for instance, should be capable of shooting the target at the distance of 5 m using tennis balls while the catapult itself should not exceed 0,5 m in each dimension. The accuracy and the shot distance are the performance criteria for the catapult project.

STEM MODULE CURRICULUM INTEGRATION: A COLLABORATIVE EXPERIENCE

Combining the two STEM-based games, the STEM Module offers salient educational potential to create an immersive engineering experience for first-year students. However, building a STEM educational framework requires complex and thorough planning within curriculum management. The following section shares the experience of building such a framework in terms of networking collaboration between SibFU and STEM-Games LLC.

The STEM Module is developed as a part of the Introduction to Engineering course with total workload of 14 weeks of the first semester including various events (see Figure 2).

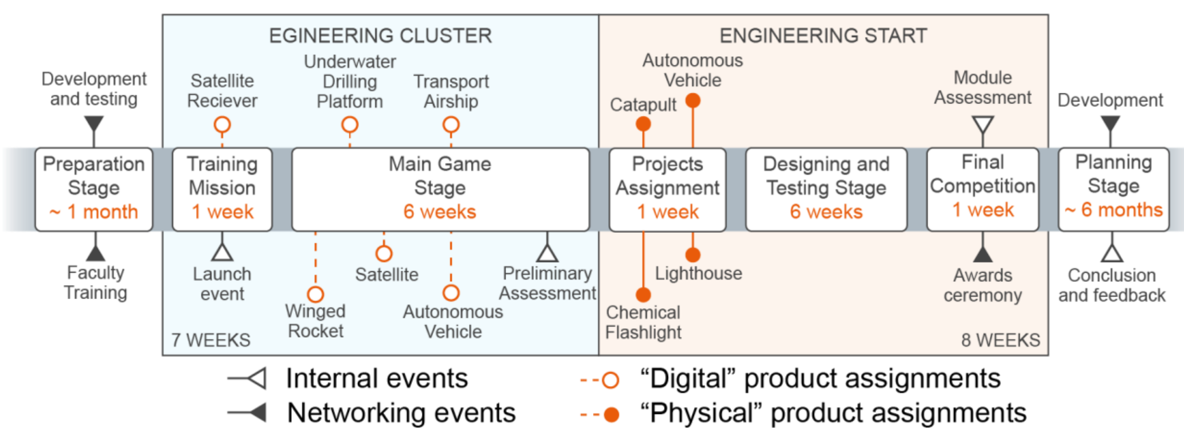


Figure 2. STEM Module timeline

The Module is updated each year after feedback and statistics data are collected, allowing to manage the reported issues, revise the content, and propose new ideas. The key points of institutions' collaboration cycle are listed in Appendix B. The STEM education framework, built around the STEM Module at SibFU, is best explained using sub-process structure:

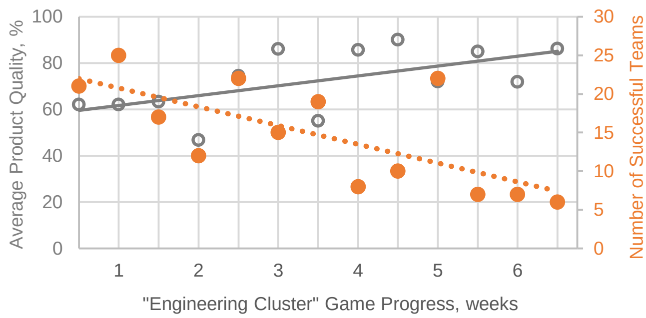
1. STEM Module
   - The Module includes both “Engineering Cluster” and “Engineering Start” games running sequentially throughout the first semester of studies
   - Regular “STEM Session” classes are a part of Introduction to Engineering course
   - “Troubleshooting Session” for teams’ leaders on a weekly basis
   - The Module workload distribution is 40% classroom and 60% self-study

2. Module Support (made by faculty, tutors, and staff)
   - Gameplay issues supported by Introduction to Engineering teachers
   - Content issues and coach sessions supported by natural sciences teachers
   - Teamwork and strategy issues supported by senior-year student tutors
   - Game website technical support and workspace maintenance

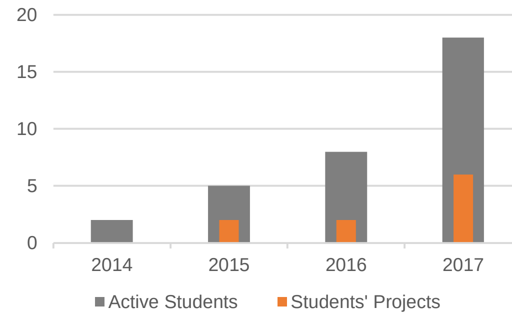
3. Module Management (made by program managers and networking partners)
   - Game activity monitoring and low progress teams support
   - Social events organization
   - Information flow, faculty and staff management
   - Game ethics and rules violation monitoring, dispute solving
   - Learning outcomes evaluation and Module performance assessment

RESULTS AND DISCUSSION

The STEM-based gaming activities are being organized at SibFU since 2015 as a result of continuous networking collaboration between STEM-Games LLC and the University. Thus, the following section shares the current results of the STEM Module project, which is being revised and updated on a regular basis. Implementation of the STEM Module in the first semester of 2017 provided students with unique learning experience and proved the positive dynamics in overall students’ performance since the launch of the STEM project in 2015. Figure 3a represents a sample of statistics gathered from the “Engineering Cluster” game platform showing the gradual increase in product quality along with establishment of several strong student teams. The data collected from students’ feedback and annual faculty reports showed the interesting tendency when active students propose their own creative engineering projects inspired by the STEM Module experience. Figure 3b illustrates the data collected from Metallurgy Engineering programme. It could be clearly seen that STEM learning helps students to discover their creative potential resulting in formation of strong teams willing to undertake their own engineering projects after the Module is completed. It is also a remarkable result of change of students’ attitude to learning process itself: The Module showed that it could be more involving, entertaining, and challenging.



a) Student teams performance overview



b) Number of projects proposed by students after the STEM Module

Figure 3. Game statistics sample and students' activity monitoring results

The STEM Module highlights:
- 120 first-year students of 3 undergraduate programs formed 26 teams
- "Engineering Cluster" resulted in 17 of 21 unique product models solved in 6 weeks with an average quality of 67 % and over 3000 of successful attempts
- "Engineering Start" resulted in 48 products passed the tests, with the total of 4 projects types: a catapult, an autonomous vehicle, a lighthouse, and a chemical-based flashlight
- The STEM Module working group included 14 student tutors, 12 faculty members, 3 staff members, and 5 program managers and officials

Learning outcomes and overall performance:
- Any product, successfully accomplished by students, is a result of applying the principles of natural sciences learned within the Module. Thus, considering Bloom's Taxonomy, it makes advanced learning result compared to traditional mode of studies
- By designing complex game products students had demonstrated the ability to solve interdisciplinary tasks, along with problem analysis and teamwork skills, although they all were stressed at the basic level. The most successful teams showed significant progress in self-study and could manage the situations of ambiguity and uncertainty during the games
- Most students reported that the engineering game context combined with project-based tasks had helped to learn the theory of natural science, along with providing teamwork experience
- The Module created a learning process beyond timetable, facilitating a long-term rapport between students and teachers, forming unique teaching-learning experience

Proposed approach for using STEM gaming activities as an educational framework proved an effective educational practice, providing freshmen students with the most rigorous and important learning activity throughout the first semester, dramatically increasing their learning motivation and overall interest to engineering profession. The potential discussed in the paper mostly depend on the effort made by institution to integrate the Module within a curriculum, including workload management, faculty training, and outcomes evaluation (Standard 3).

Inferring from the networking experience between STEM-Games LLC and SibFU, the benefit of shifting to STEM learning in the first year of studies is defined by the following:

1. Students get familiarized with project-based activities at the earliest stage (Syllabus 2.1)
2. Positive change of students' attitude towards natural science (Syllabus 1.1)

3. In-game projects require higher levels of knowledge attainment and their integrated application (Standard 7)
4. Native for modern students form of education which takes learning beyond the classroom
5. Personified learning with student's responsibility for product quality.
6. Fostering students' engineering vision of product within a lifecycle (Syllabus 2.3)

CONCLUSION

Implementation of STEM technologies as a holistic education framework for the first-year undergraduate students of SibFU demonstrated an opportunity to integrate an engineering with the content of natural sciences, which fully complies with CDIO principles. The STEM Module games "Engineering Cluster" and "Engineering Start" allowed to engage students with the problems of engineering profession, showing significance of theoretical knowledge use for solving practical engineering problems. Intercurricular integration of the Module and active faculty involvement showed significant increase of learning efficiency. In general, the benefit of STEM learning is in creation of valuable and salient learning experiences for young students, fostering their engineering thinking and encouraging for further active study at university.

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BIOGRAPHICAL INFORMATION

Aleksandr Arnautov, Ph. D. is a senior teacher of Metallurgy Engineering Department. He is currently a coordinator of CDIO Office at SibFU. His current research focuses on digitalization of learning.

Natalia Gafurova is a Professor in Education and Pedagogy, and a Counsel to the Rector of Siberian Federal University. She is currently the leader of CDIO project at SibFU. Her research focuses on education development, didactics, and digitalization of learning.

Yaroslav Fadeev is a postgraduate student at Moscow State University and STEM-Games LLC lead developer. His current research is focused on the development of novel educational games, simulations and the assessment of their efficiency.

Viktor Dyomin is a chemistry teacher at Moscow State University and the founder of STEM-Games LLC. His current activity is aimed at development of engineering competitions and games.

Corresponding author

Dr. Aleksandr Arnautov
Siberian Federal University
79 Svobodny pr., 660041 Krasnoyarsk, Russia
+7 391 206 2165
aarnautov@sfu-kras.ru

APPENDIX A

Table A. “Engineering Cluster” Production Stages

Production Stage	Team activity
1. Project Start	Start a new product with custom parameters or picking up Product Order from game pool
2. Requirements Analysis	Studying requirements and limitations of each product in chain, analysing products’ parameters cross-relations
3. Designing	Calculation of product models. The challenge is in the lack of strategy given and product compatibility awareness
4. Simulation	Game engine simulates product model using students’ parameters. Simulation log shows product’s resulting specifications. PDCA cycle allows students to make iterative corrections
5. Production	Checking if required products are in stock. Final product quality is defined by quality of components. After finishing the product, the production line could be built, allowing produce the same product for cost price
6. Product Implementation	Two options for finished product: a) product is stored for market or further production b) product is utilized (deleted)

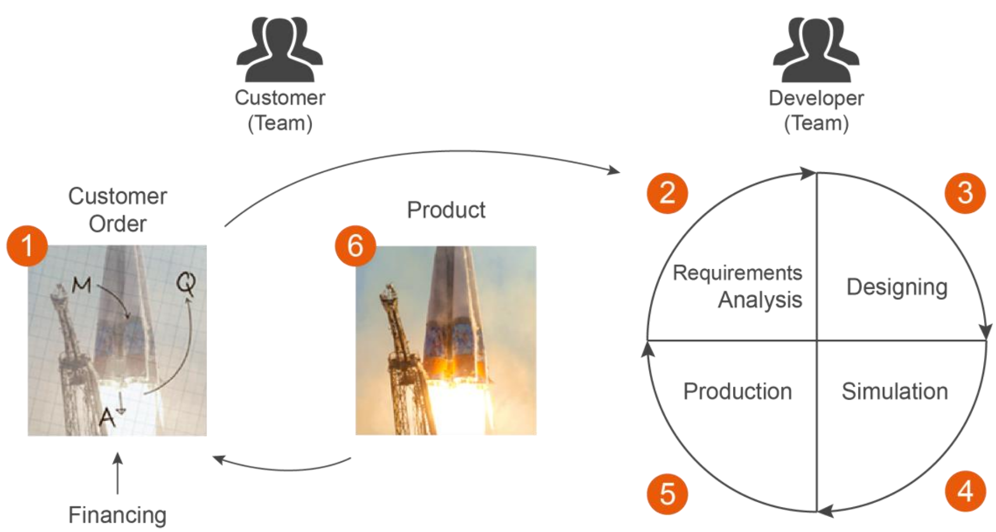

Figure A. In-game production cycle

APPENDIX B

Table B. STEM Module Development Cycle

Stage	SibFU	STEM-Games LLC
Background of collaboration	Facing the need for new educational practices, and curriculum development	Development of educational games and engineering competitions for youth
Form of collaboration	Networking agreement for developing joint educational practices	
Defining the structure *6 months before launch*	The Module of two STEM-based games as a part of "Introduction to Engineering" course for the 1st year students	"Engineering Cluster" game as a theory-based online STEM game, and "Engineering Start" game as a practice-based project competition
Defining the content *6 months before launch*	Introduction to Engineering and Natural Science courses integration. Syllabi development, incl. learning outcomes planning	Selection of contextual engineering tasks based on the requested content and workload
Module Development *3 months before launch*	- Curriculum design - Documentation approval - Resources planning - Assessment planning	Module tasks and activities development
Faculty training *1 month before launch*	Training seminar for faculty and student tutors. Game preliminary testing	- Training seminar agenda - Expert visit to SibFU - Feedback collection
Module launch *1 week*	- "Engineering Cluster" launch event - Registration of student teams - Introductory game session	Documentation and manuals supply. Technical support and help desk
"Engineering Cluster" game *6 weeks*	- Regular classes and self-study - Troubleshooting sessions - Activity monitoring - Preliminary assessment	Technical support and help desk
"Engineering Start" game *7 weeks*	- Projects assignment - Workspace organization - Materials and Tools supply - Activity monitoring	Documentation and manuals supply. Technical support and help desk
Final Competition *1 week*	- Event hosting - Awards ceremony - Feedback collection - Learning assessment	- Game data analysis - Expert visit to SibFU - Feedback collection
Module Development *After Module conclusion*	Troubleshooting session based on feedback analysis. New ideas proposal. Module development strategy based on needs analysis. Expansion of collaboration range, further joint projects.	

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A NEW METHOD FOR MANUFACTURING ENGINEERING PROJECTS

John Clausen

Dept. of Innovation, Design and Manufacturing, Technical University of Denmark

ABSTRACT

This article focuses on challenges and problems related to Manufacturing Engineering Projects conducted by students in companies, and offers a new method to address these challenges.

The goal of Manufacturing Engineering Projects will normally be to improve the operational performance in some functional areas of a company. Due to the fact that many different causes might influence the operational performance, these projects are complex by nature which is challenging. It is not obvious how such problems should be approached. Often it seems to be difficult for students to formulate a comprehensive problem statement or problem specification for a project, and to decide exactly what they should investigate. It also seems to be quite difficult to design and build feasible solutions based on their findings. Literature offers a range of different methods and techniques to run projects and to solve problems. These methods and techniques may be valuable elements, but they do not constitute a complete and sufficient methodology to deal with Manufacturing Engineering Projects. So in general there is a need for a comprehensive and systematic method which can support the formulation of a problem statement and guide the selection of investigations that should be performed in a Manufacturing Engineering Project, as well as support the generation of ideas for solutions.

At the Technical University of Denmark we have worked with the development of such a method. Based on experience from a large number of projects in companies conducted by students in the BSc. Manufacturing Engineering Study Programme, two new tools have been developed to support students in conducting Manufacturing Engineering Projects. One is a general phase model for Manufacturing Engineering Projects, and the other is a tool to support problem analysis. The latter is called a ‘Problem Hierarchy’ and it includes basic ideas from ‘Cause & Effect Analysis’ also known from Total Quality Management (TQM) and Lean Management, and from the method ‘5 times why’ which comes from Root Cause Analysis in Maintenance Engineering.

As a final step the phase model and the Problem Hierarchy are integrated into a new generic method that offers a systematic approach and seems to address the challenges.

KEYWORDS

Problem Hierarchy, Cause & Effect Diagram, Manufacturing Engineering Phase Model, Standards: 1, 6, 7, 8.

INTRODUCTION

A manufacturing company finds the productivity of one of their semi-automated production lines to be low overall, with the productivity level also varying too much. Therefore they have asked a group of students to look into this problem and come up with suggestions for improvements. This is a typical example of a Manufacturing Engineering Project. How can the students approach such a problem or similar problems? This paper suggests a systematic problem solving approach. But first we will take a look at Manufacturing Engineering Projects and their relationship to CDIO.

The challenge of Manufacturing Engineering Projects

Manufacturing Engineering students must train and develop their professional skills by conducting real-life projects in companies. As illustrated by the example above such projects will usually focus on improving the operational performance in a specific area where the company has identified a ‘high-level’ problem in their production. The students will study the current operations, collect data, interview key employees, and suggest improvements in processes, organization and technology. A typical time frame for such projects will be 2-6 months.

Manufacturing Engineering projects are special and challenging for several reasons:

The study ‘object’ is a working company with employees and a production schedule. This leaves very limited room for performing experiments with changes of procedures or technology. In general students or consultants are bound to be passive observers. Recommendations that should improve the company’s future operation must be based on studies of the company’s current activities plus theoretical considerations and calculations. Changes of working procedures, machines or equipment, computer programs etc. are typically so expensive and demanding to implement that it is not possible to test different ideas before it is decided to actually implement them. This is a key point. It puts responsibility on project groups to ensure that suggested improvements will actually improve operations, and that the company is able to implement them. They must also convince the company about this.

In order to develop proper solutions it is necessary to fully understand all of the factors that influence the operational performance under consideration, and which of these factors it will be possible to influence. However this is quite complex since there is not a simple relationship between causes and effects in this area. Many different factors might influence an existing problem. Therefore it is difficult to decide which type of analysis a project group should perform, and how ideas for solutions could be generated.

Literature offers a wide range of general methods and techniques to support project management in different fields of engineering; e.g. Life-cycle models to support software development. Different methods and techniques for problem solving are also available. Of course such methods and techniques can also be valuable in relation to Manufacturing

Engineering Projects, but there seems to be a lack of an overall method or methodology to address the specific challenges related to these projects. There is a need for a method to support the formulation of a problem statement and guide the selection of investigations that should be performed in a project and finally support the generation of ideas for solutions.

Manufacturing Engineering Projects and CDIO

Manufacturing Engineering Projects are closely related to the concept of CDIO. Directly or indirectly they include aspects from all CDIO phases: Conceive, Design, Implement and Operate.

In the initial stage of a project it is necessary to analyse the current situation to fully understand the operations and the causes of the problems that the project is set to solve. This constitutes the Conceive phase.

Based on the findings from the analysis, solutions must be developed, which will represent improvements. This is a clear Design phase, and since the focus of the design will be on improving future operations it might be called 'Design for Operation'.

In general, manufacturing engineering projects conducted by students will not include implementation of suggested solutions. Implementation is a company responsibility. Therefore company managers and employees must be directly involved in the implementation of suggested changes. However, individual students from the project group will often participate, acting as consultants or student employees. The timing might be a problem - when a project is finished it will normally take some time for the company to study the recommendations, decide upon changes, and define a proper period for the implementation. Most often this will not fit with the students' study calendar, because a project group cannot wait several months after the Design phase to engage with the company again.

Although implementation is not directly part of Manufacturing Engineering Projects performed by students there is still a strong indirect relationship. The project must consider exactly what it takes to perform a successful implementation. Recommendations on how to perform the implementation should be part of all Manufacturing Engineering Projects.

The same goes for 'Operate'. Since the goal of the project is to improve the operational performance, all recommended changes must support this. A solution, which does not improve the operations when it is implemented, is not a solution at all. Therefore a project group must be certain that the desired improvements will actually occur when the recommended changes are implemented. They must also be able to convince the company that the positive outcome will happen, as this will be the basis for the company's decision on whether or not to carry out the suggested changes.

A NEW METHOD

In the BSc. Study programme in Manufacturing Engineering at the Technical University of Denmark two tools or methods have been developed to address the challenges in Manufacturing Engineering Projects and support students. The first tool is a fairly simple and straightforward phase model for Manufacturing Engineering Projects. The second tool is a method for handling high-level problems in companies called a Problem Hierarchy. Both of these tools have showed to be beneficial in project work, but the real power appears when they are combined into a new generic method, as explained in the following sections.

The Manufacturing Engineering Phase Model

The phase model is shown in Figure 1

The starting point is a problem area within a company. Someone in the company sees a potential for improvements and initiates a project with the goal of finding solutions. From here, the project goes through 8 natural phases:

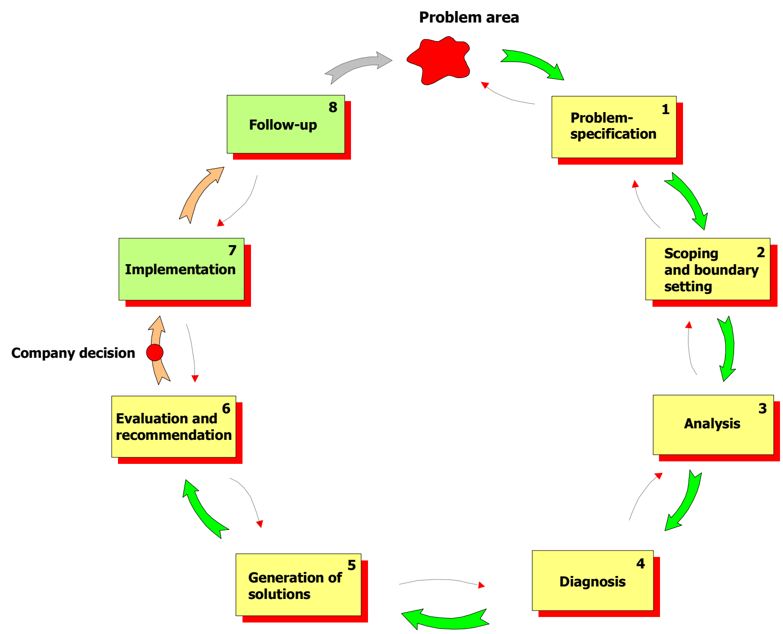

Figure 1: Phase Model for Manufacturing Engineering Projects

1st phase is a problem specification or goal setting phase. The project group must specify in detail what they want to achieve or improve during the project, and what is not included. A preliminary insight into the company and its problem area is required in order to formulate a qualified problem statement for a project. It is important to devote significant attention to this, because it forms the basis for the project's following activities.

2nd phase is a general scoping phase where company restrictions, resources and the time factor are considered in relation to the goal.

3rd phase is the analysis which is necessary in order to understand the system in depth and find out, which factors influence the results and which changes are possible.

4th phase is a diagnosis including general conclusions based on the results from the analysis conducted. This phase will act as a stepping stone for the following generation of solutions.

5th phase represent the generation of practical solutions or elements of solutions in order to fulfill the problem statement. In this phase it is necessary to be creative and explore all 'avenues' and solutions, which in any way could influence the result in a positive way.

6th phase represent a more detailed study of the solutions or elements of solutions. First it is necessary to cut down the number of solutions or combinations of solution elements from phase 5 to a small number. Second it is necessary to evaluate the remaining solutions or elements carefully. This will often include an investment analysis or multi criteria analysis. The result will be recommendation of one specific solution or a few alternative solutions. Recommendations on implementation of the suggested improvements must be part of the solution. When this phase is finished, the company must decide whether to implement the suggested solution or part of it. Of course the work must provide a sufficient amount of information as a solid basis for this decision.

7th phase is the implementation. This phase includes implementation of technical or operational changes, training of operators etc.

8th phase is a follow-up to check if the implemented changes fulfill the original project goal.

This general model is well suited for manufacturing engineering for several reasons. The phases represent a logical sequence of activities, which are all necessary in order to find good solutions to the problems at hand. The process encourages the project goal and any restrictions to be decided very early in the process, which focusses efforts in the most cost efficient way. It furthermore encourages ideas on solutions to be created not in a too early stage, but rather later on when the project group has gathered insights into the processes and is familiar with the company activities. In relation to CDIO phases 1 and 2 represent Conceive, phases 3-6 Design, phase 7 Implement and phase 8 Operate.

COMPLEXITY IN MANUFACTURING ENGINEERING PROJECTS

The element of complexity

It has previously been explained why problems in manufacturing companies in general are complex by nature. In Manufacturing Engineering Projects we need methods to support the generation of solutions that deal with this complexity. This section will describe two existing methods: 5 x Why and Cause & Effect Diagrams. Finally the Problem Hierarchy will be introduced as an enhanced method.

Root Cause Analysis and 5 x Why

In Maintenance Engineering, Root Cause Analysis has been developed as a discipline. It comes from the concepts Total Quality Management, Lean Manufacturing and 6 Sigma. In Root Cause Analysis, a method called 5 times Why is recommended. It is originally developed by Sakichi Toyoda and Taiichi Ohno at the Toyota Motor Corporation. The principle here is to find the root cause of a problem by continuously asking 'why?' a number of times, and follow the answers. The theory states, that in this way you will always find the basic reason called the root cause in no more than 5 successive steps.

A simple example could be a machine producing too many items with errors. The first question is 'Why is the machine producing too many items with errors'? The answer could be that the raw material does not have a consistent quality. Second question could then be: 'Why is the quality inconsistent'? The answer to this might be that the quality is sensitive to temperature, which sometimes gets too high. The third question could be: 'Why is the temperature sometimes too high'? and it could be found, that the temperature gets too high, when the material waits for more than a few minutes inside the machine due to stops. In this way the root course have been found in only three steps as illustrated in Figure 2.

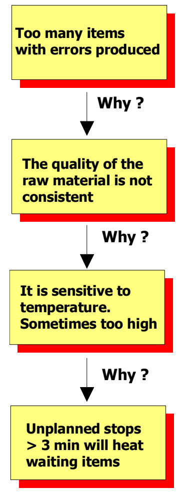

Figure 2: Example of 3 times Why

The method 5 times Why is based on the idea that for each question, we go a layer deeper and change from a more general question to a more specific one. It also assumes that there is one specific root cause, and that the relationships are simple and direct. This is true with many technical problems. But as stated above, this is not the case for operational problems in companies. So in general, Root Cause Analysis and 5 times Why, cannot be used as the sole method for solving these kind of problems.

Cause & Effect Diagrams

A method or principle, that actually deals with complexity in relation to problem solving is the Cause & Effects diagrams developed by Dr. Kauro Ishikawa. These diagrams are also called Ishikawa diagrams, CE-diagrams or fishbone diagrams. The idea is, that all factors that has some influence on a specific problem, are listed in a fishbone structure. Traditionally the following 'M'-factors are considered in manufacturing : Man, Machine, Measurement, Method, Materials and Environment (Mother nature) as seen in Figure 3. Often also Management and Maintenance are included. A few references could be: (Nasaaki Imai, 1986), (Melnyk & Denzler, 1996), (Frank M. Gryna, 2001), and material from CQE Academy.

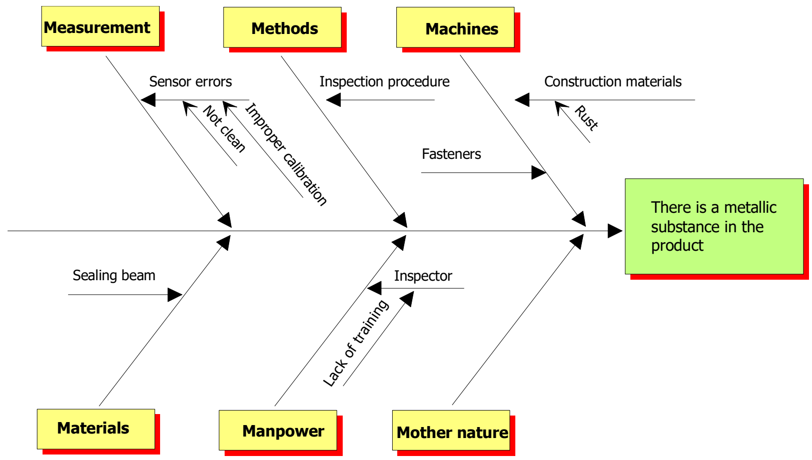

Figure 3: Example of a Cause & Effect Diagram

Cause & effect diagrams have gained widespread usage. They represent a logic and systematic approach to problem solving. But they have a few drawbacks. I will mention two:

- The use of Cause & Effect Diagrams has not developed into a consistent generic method. In literature they are typically used to solve specific individual problems like the one in Figure 3. They might be used for specific problems in a project but they are not suited as basis for a general method.

- Cause and Effect diagrams are difficult to read and difficult to draw due to the shifting orientation of lines and text.

The Problem Hierarchy

The Problem Hierarchy includes logic principles from both 5 x Why and Cause & Effect Diagrams. It is developed to overcome the drawbacks mentioned above, and to function as basis for a general method for Manufacturing Engineering Projects.

A Problem Hierarchy is built up of 'problems'. The general principle states that all problems are decomposed into sub problems which could possibly influence the problem above directly, and hence could be seen as possible causes. The process starts with a selected high-level problem at the top, and it continues as long as each decomposed sub problem in the hierarchy can still be further broken down, into even more detailed sub problems or causes.

The result of this decomposition process is a hierarchy of problems with more general problems at the top, and more specific ones below. It represents a decomposition of a high level problem into a hierarchy of more and more specific problems below. Each of the lower level problems represent possible causes for the problems above. However the low-level problems in the bottom of the hierarchy are much easier to deal with than the more abstract problems at the top. They are much easier to study or to solve. That is the reason for the decomposition process.

To illustrate the process let's now go back to the general problem of productivity from the introduction paragraph. We specify the general problem: 'Productivity is too low, and it is varying too much' as the high-level problem in the top of the Problem Hierarchy. This is a rather abstract problem, which is difficult to address directly because it is too complex. Many factors could lead to low productivity and perhaps other factors are driving the issue of varying productivity. Therefore It has to be decomposed into more specific problems. Possible reasons for low or varying productivity could be inadequate production planning or problems related to operators, machines or materials. None of these decomposed problems can be handled directly since each of them may be caused by several underlying factors. Therefore they have to be decomposed further as illustrated in Figure 4.

The decomposition process continues to a level of possible problems in the bottom of the hierarchy, which can be addressed or analyzed directly. As an example, it is possible to investigate directly if the operators have got the right skills, if they are sufficiently motivated or if the quality of planning data is good.

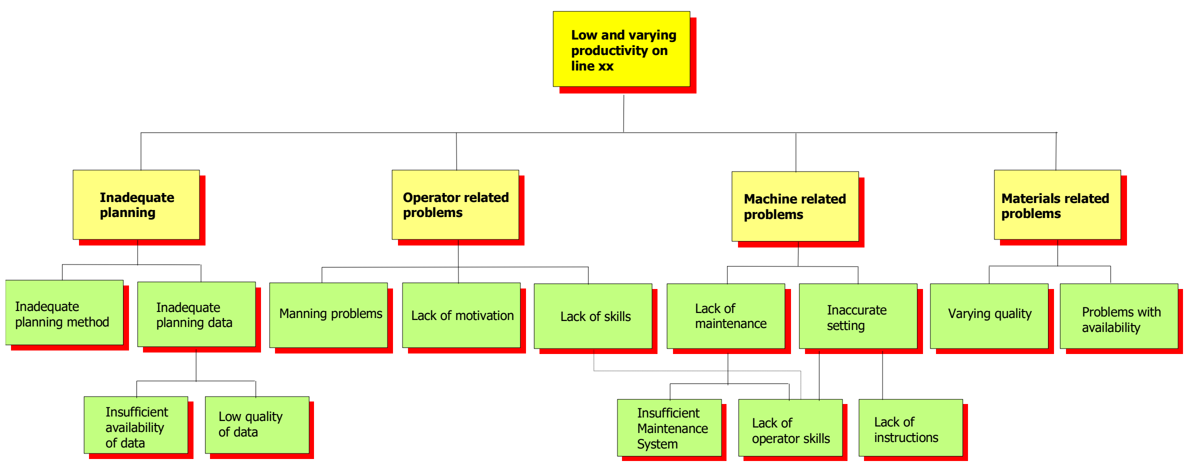

Figure 4: Problem Hierarchy of a productivity problem

A Problem Hierarchy is easy to read and understand, and it is fairly simple to work with. Of cause the text must be very short when the boxes are small. As illustrated in Figure 4, there might be a practical problem with space, when a model has many boxes in a decomposed layer, but this is easy to handle using a modern drawing program.

The quality of a decomposition

Can we be sure, that all important factors that influence the top level problem in a Problem Hierarchy are included? That depends on the quality of the decomposition. In principle all important factors should be included when a specific problem is decomposed. But that presumes an insight, which is not always present. If an important factor is omitted, it is not considered and decomposed further. Therefore it is necessary to be careful, and work intensively with the decomposition process. In a project, the Problem Hierarchy should be changed continuously as new insight arise.

Hierarchy or network?

Sometimes a specific problem in a Problem Hierarchy could relate to more than one high-level problem. As an example: Both 'lack of maintenance' and 'Inaccurate setting' in Figure 4 could be caused by lack of operator skills. In Figure 4 this problem is listed as a machine related problem, but of course it is also an operator related problem as indicated. So in this case three different high-level problems are decomposed into the same lower-level problem.

If a low-level problem is allowed to relate to more than one problem above, the structure is not a true hierarchy. From a technical point of view it is a network. In a project we could handle the decomposed structure of problems as a network by drawing all relevant relations accordingly. However this might lead to a diagram, which is more complicated to read and understand due to crossing relation lines. It is much easier to work with a hierarchy. Therefore it is recommended to keep the structure as a hierarchy, and instead duplicate any low-level problems that relate to several higher level problems, and add a comment to the diagram. For simplicity we will proceed with Figure 4 in the current form.

How to use the Problem Hierarchy in a project

As stated earlier the Problem Hierarchy represents possible problems or causes. They are not necessarily actual problems or causes in the company. In order to find effective solutions to the top-level problem the project group must investigate which of the possible problems in the Problem Hierarchy are actual problems in the company.

The best way to do this is by using a bottom-up approach and start with the low-level problems in the bottom of the Problem Hierarchy. The reason being that these problems are much more specific and easier to investigate than the more abstract problems above.

In this way the problems at the bottom of the Problem Hierarchy act as a guideline for which analysis to conduct in the project. From Figure 4 the following investigations could be listed:

- The planning principles and analysis of OEE (Overall Equipment Efficiency)
- The availability and quality of planning data
- The availability of operators
- The motivation of the operators
- The maintenance system
- The skills of the operators
- Instructions and SOP's (Standard Operation Procedures)
- The variations in material quality
- The availability of materials

The Problem Hierarchy can now be updated with investigations shown as 'Investigation boxes' as illustrated in Figure 5:

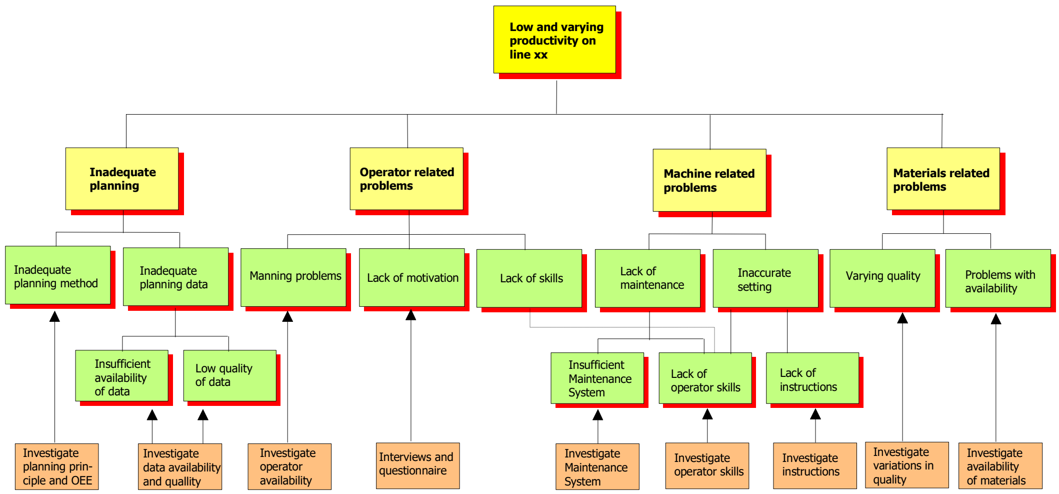

Figure 5: The productivity Problem Hierarchy with investigation boxes

When the studies have revealed which of the potential problems are actual real problems in the company these problems must be solved. Since the problems at the bottom of the Problem Hierarchy are detailed and specific, it should be possible to find and implement relevant solutions. When the actual detailed problems in the bottom of the Problem Hierarchy are solved, the logic from the decomposition process will ensure that the high-level problems are solved as well. Assuming here that the Problem Hierarchy is well developed, and all important factors are included.

COMBINING THINGS INTO A NEW GENERIC METHOD

In a project the development of a Problem Hierarchy should be linked directly to the phase model in Figure 1. Since the problem hierarchy contains possible problems it can be generated very early in a project. In fact, at a point where the project group has not yet gained detailed knowledge about the company and the activities. It is necessary to have a solid definition of the top-level problem in order to start the process and naturally this is possible in relation to the formulation of a problem specification for the project in phase 1. Therefore the first version of the Problem Hierarchy is suggested to be developed in phase 1. From there on is should be used as a roadmap for the project and changed successively based on further insight.

In the Analysis phase the Problem Hierarchy will act as a consistent and logical guideline for which detailed studies or analysis the projects group should perform. This is supported by showing them as ‘Investigating boxes’ as shown in Figure 5.

Later, when the results from the analysis phase are ready, the Problem Hierarchy should be updated to show which of the possible problems are identified as actual existing problems that need to be solved. This can be done by marking the relevant boxes in the diagram. An example is shown in Figure 6. The investigations here have revealed four areas that need to be improved:

- The availability of correct planning data must be improved. Sometimes data is missing or late, and sometimes there are too many errors.
- The availability of operators is a problem. Often there are too few operators which result in too much waiting time.
- The skills of the operators are not sufficient in relation to maintenance and required setting of the machinery.
- The quality of materials varies too much. This causes stops and errors on the production line.

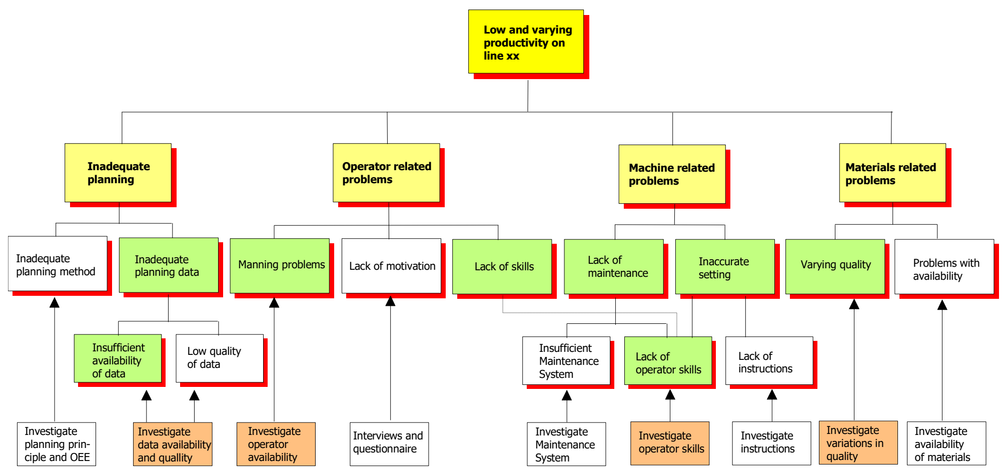

Figure 6: The productivity Problem Hierarchy with recognised problems marked

In phase 5 and 6 the Problem Hierarchy supports the generation of solutions. It gives a complete visual overview of all low-level and high-level problems that needs to be solved. This makes it easy to measure or compare ideas for solutions against these needs.

At the end of the project the Problem Hierarchy specifies which problems have been addressed through the work. It also shows the problems and areas that have not been addressed. This is important information because it could lead to identification of a need for future projects in the company.

The suggested coupling between the phase model and the Problem Hierarchy during a project constitutes the recommended generic method for Manufacturing Engineering Projects. It is illustrated in Figure 7:

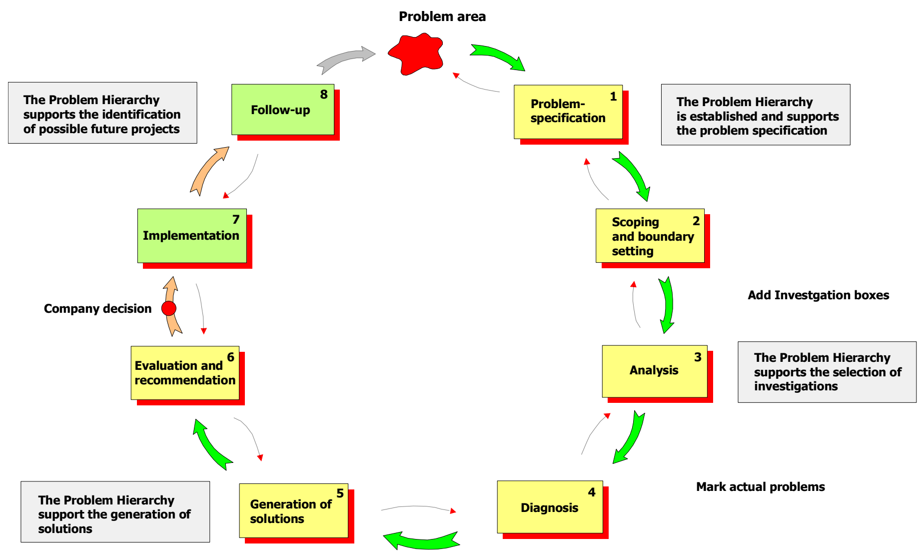

Figure 7 The Problem Hierarchy method to support project activities

EXPERIENCES AND CONCLUSION

In the BSc. Study programme in Manufacturing Engineering at the Technical University of Denmark, students are running projects each study semester. Here they train to use their skills from the ordinary courses in a problem oriented and interdisciplinary context. During their 4th semester they are running projects in companies where the project group and a company agree upon a problem area that has to be improved. Normally these projects will focus on improving the operational performance in some areas e.g. a production line or some business processes. Since the companies, their processes and their problems are different, these projects are quite unique as well. However we have gained some common experience over the years from these projects.

In general, the students are quite qualified in performing specific analysis in companies, but in a project context they find it difficult to specify relevant goals for the projects and decide on which analysis and investigations they must perform in order to be able to generate good solutions, as stated previously. This is even if we have been teaching the students principles on how to run projects for many years and also the basic principles of the Problem Hierarchy. We have seen this as lack of a clear methodology for such projects and consequently we have developed a new course: Scientific Theory and Manufacturing Engineering Methods focusing on methodology. In relation to this course that is taught in parallel with the projects the Phase model in Figure 1 and the Problem Hierarchy have been developed as fundamental models, and they have been integrated into the generic method for handling manufacturing engineering projects that is described in this article.

The new course has now been active over a few semesters. Since the projects are supervised by different teachers, we have not collected statistics, but the conclusion so far is that the method described has been adopted well by the students and used with success in many projects. These students find that the method actually gives them a good and consistent basis for their work. In general the method described seems to fulfill the requirements from the introduction paragraph for a generic method to support Manufacturing Engineering Projects.

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BIOGRAPHICAL INFORMATION

John Clausen, Ph. D. is associate professor at the Department of Innovation, Design and Production at Center for Bachelor of Engineering Studies at The Technical University of Denmark. In 2000-17 as head of the Manufacturing Engineering Study Programme he was focusing on developing the Manufacturing Engineering Study Programme according to principles of Problem Based Learning and CDIO. Now as partly retired he is focusing on supervision and teaching in Manufacturing Engineering Methods and Company Systems.

Corresponding author

John Clausen
Center of Bachelor Engineering Studies
Technical University of Denmark
Lautrupvang 15
DK-2750
+45 4045 8262
johcl@dtu.dk

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ON THE IMPORTANCE OF PEER INSTRUCTION IN GROUP DESIGN PROJECTS

N. Chalashkanov, A. Bhangaonkar, R. Thornton

Department of Engineering, University of Leicester, UK

ABSTRACT

This paper is focused on the importance of peer instruction in a collaborative design project and particularly on the knowledge transfer between fourth year (project managers) and second year (design engineers) students. A subtle change introduced in the last two years was that the prototype requirements for the second year teams were the same as the requirements that the fourth year project managers had to meet two years previously. This had a positive impact on the esteem of the project managers and increased their self-confidence allowing them to provide more relevant technical guidance to the second year students during the project. As a result, design teams were more likely to produce functioning prototypes, which also met a greater proportion of the design requirements. In order to understand the reasons behind the improved performance of the teams, the fourth year students were asked to assess their confidence and capability to manage design group projects in a survey. The results of this survey and its findings are presented in this work.

KEY WORDS

Group work, Design and build projects, Peer instruction, Standards: 5, 6, 7, 8

INTRODUCTION

Design and build projects are key aspects of the CDIO approach to teaching (CDIO Initiative, 2018). Often group projects are considered to present numerous advantages over individual projects since they allow transferable skills to be developed alongside technical expertise and management (Biggs, 2003). Group projects are also part of the accreditation requirements of professional bodies such as the Institution of Mechanical Engineers (IMechE, 2017), The Institution of Engineering and Technology (IET, 2017) and others. However there are also concerns about the use of group work in the engineering curriculum and especially related to the assessment of individual student's contribution to the project (Thompson et. al, 2015).

One of the limitations of project based learning is that the assessment is not straightforward and individual skills may get stifled or remain unrewarded. However, this method has a great influence on students' future learning, although effects in the short term may be unnoticeable. Participating in projects helps them to look at each other as sources of information and encourages peer learning. Mentoring is required to help them set-up and manage self-monitoring systems. A critical aspect is the review of the allocation of work to individuals and progress reviews at various stages. Bottlenecks in resource provision need to be addressed at the start along with disagreements between the members (Gibbs et. al., 1992).

Projects have a three-fold impact on student learning (Fry et al., 2014). First, they provide a means to introduce research culture in the undergraduate curriculum. Second, it encourages them to stay on as research students. And third, it emphasises the responsibility that the learners have to take up for their own learning and knowledge building. Having projects as a part of the curriculum also promotes the link between teaching and research. The role of a supervisor subtly moves towards being a facilitator.

Engineering Design forms the core of all undergraduate curricula (Aerospace, Electrical & Electronic, General and Mechanical Engineering) in the Department of Engineering, University of Leicester, UK. The largest element of the Design curriculum is the second year 'Integrated Engineering Design' module, which is taught by means of a Design and Build group project. Second year students work in multidisciplinary design teams and apply their course specific knowledge to the design and manufacturing of an integrated system. A fine balance has been achieved between structured and unstructured nature of design projects. Although the specifications for what needs to be achieved are strictly defined, the concepts and design solution are not prescribed. As a result, every year, there is a plethora of innovative designs used by the groups for achieving the objective. Each design team is project managed by fourth year (Master's level) engineering students. Also associated with each team are: an academic staff member, technicians and a Visiting Design Professor (VDP). The academic staff member acts as a supervisor and provides technical advice to the team, and the technicians provide practical guidance regarding the electrical and mechanical aspects of the prototype manufacturing. The VDPs are senior industry leaders who provide high-level feedback to both design teams and project managers, and their role is approved and supported by the Royal Academy of Engineering (RAEng). Associating multiple personnel, with varied levels of experience, for mentoring the groups provides a broad base of skill set that remains available to the groups for consultation, and irons out any weakness of an individual supervising the group. It also makes the level of support offered quite uniform across the groups.

In the past, the students have been tasked with a different design project each year and the projects topics varied from sustainable energy to unmanned aerial vehicles (Chalashkanov, 2014). However, over the years some fourth year students have expressed concerns about managing projects that they have no technical expertise in. In order to assess the importance of this factor, in the academic year 2016-2017 it was decided to repeat the design task given to the students two years before. The implication was that the majority of the fourth year students would have done the same project in their second year of study. The only exceptions were students who had spent a year working in industry or studying abroad. The project topic was a model hovercraft, and the requirements specification was similar to the brief given to the students in 2014-15 with the exception of some minor technical details.

In 2014-2015 there were 24 design teams. Each team was required to produce a functioning hovercraft prototype by the end of the module and all prototypes were assessed by the panel of VDPs in a Design Competition. Only one out of the 24 teams managed to produce a fully functional prototype. The rest of the prototypes met the design requirements only partially. In contrast to the 2014-2015 design project, only one team produced a prototype which was not fully functional in the 2016-2017 design challenge.

The difference in performance between the two cohorts was attributed to the experience of the fourth year project managers. Because the majority of the fourth year students had previously worked on a hovercraft project (as design engineers in their second year of study) they were in a position to provide better technical guidance to the second year students in their team. In general they showed increased confidence in leading and managing the teams, which was also noted by the VDPs who assessed them.

In order to gain a better understanding of the students' perceptions and gather observations about the fourth year students' confidence and capability, the fourth year cohort was surveyed in the 2017-18 academic year. As before, the group project had a similar requirements specification to the project given to the students two years previously. The results of the survey and its findings are presented in this work.

METHODOLOGY

The fourth year project managers were asked to complete a questionnaire regarding their confidence and capability to manage design and build projects. The questionnaire was anonymous, however the students were asked to provide some basic demographic data in relation to their degree specialisation and previous experience. The questionnaire consisted of 11 questions in total. The first 3 questions were to establish the demographics of the cohort. The remaining questions were probing their self-assessed confidence and capability to manage engineering design teams and their perception of what skills are most important to a project manager. For the purposes of the study, confidence and capability were described as:

- Confidence – Someone who self-assesses as being very confident would feel comfortable approaching a problem or task, with little or no 'expert' support (e.g. from academic mentors).
- Capability – Someone who self-assesses as having a high capability would believe they had the necessary skills and knowledge to attempt a problem or task, with little or no additional tuition (e.g. from mentors or other resources).

The students were surveyed in a scheduled design session using paper questionnaires. The participation in the survey was on voluntary basis and each fourth year project manager attending the session was given a questionnaire. In total, 41 completed forms were collected from 51 students enrolled in the course, indicating 80% participation in the survey.

The first question asked the students to indicate their degree. The majority of students, 24, were on the Mechanical Engineering degree, 9 – Aerospace Engineering, 4 – Electrical & Electronic Engineering and 3 – General Engineering. One student did not indicate their degree specialisation.

The second question asked the students to indicate if they have completed a year in industry or year abroad (both options are available to students who have successfully completed the first two years of their degree). 29 students had completed neither option, 2 students had studied abroad and 9 students did an industrial placement for one year. Again, one student did not answer that question.

The third demographic question asked the students to indicate the topic of the group project they had completed in their second year of study. 27 students had done a similar project to the one they were managing, 12 students had participated in a different project and two students did not indicate their prior experience with group design projects. For the purpose of analysing the results of the survey, the students who did not indicate their prior experience in group projects were grouped together with those who participated in a different project, giving a total of 14 students in that category.

Because of the small number of students enrolled on courses different from mechanical engineering, it was not possible to analyse the results of the survey in terms of degree specialisation.

RESULTS

Table 1 shows a summary of the responses of questions 4-7 in the questionnaire. These questions aimed to probe the fourth year students' perceptions about their own confidence and capability to manage the current design project and provide technical guidance to the second year students. Each question required the students to assess their confidence and capability between 1 and 5, with 1 being low confidence/capability and 5 being high confidence/capability. The mean scores for each question 4-7 are given in Table 1. The results in Table 1 are given for the cohort as a whole, and for two distinct sub-groups: students who have participated in a similar project before (Group A) and student who have done a different project from the one they are currently managing (Group B - the majority of the students in these category have done an industrial placement for one year).

The mean ratings are very close in both sub-categories. It should be noted that the number of students who did the same project in their second year as the one they are managing is nearly twice than the number of students who did a different project, which is also reflected in the results for the entire cohort. The overall results for the cohort are biased to the responses provided by the larger group of students.

Table 1. Mean responses from survey questions 4 – 7.

No.	Question	Same project (Group A)	Different project (Group B)	Entire cohort
4	Please indicate your **confidence** in managing this year's second year design project.	4.0	4.2	4.0
5	Please indicate your **capability** in managing this year's second year design project.	3.9	4.1	3.9
6	Please indicate your **confidence** in providing technical guidance to the second year students.	3.6	3.9	3.7
7	Please indicate your **capability** in providing technical guidance to the second year students.	3.9	3.9	3.9

Table 2 summarises the responses to questions 8 and 9 for the entire fourth year cohort. The majority (approximately 70%) of the students indicated that they feel both more confident and more capable to manage a similar project to what they have done in the past. 29% of all students expressed an opinion that the project topic does not make any difference, and only a small percentage of the students indicated that they would feel more confident managing a different project.

Table 2. Mean responses from survey questions 8 and 9. All students.

No.	Question	Similar project	Makes no difference	Different project
8	Please indicate whether you would have more **confidence** managing a project that is technically similar to or different from those you have participated in the past.	69%	29%	2%
9	Please indicate whether you would have more **capability** managing a project that is technically similar to or different from those you have participated in the past.	71%	29%	0%

The breakdown of the responses for the two sub-groups (Group A and Group B) described above is given in Tables 3 and 4, respectively. It is noteworthy that the responses to question 9 of both groups are effectively the same. However, there is a significance difference between Group A and Group B in their responses to question 8. 78% of the students in

Group A indicated they are more confident managing a similar project to their prior experience and 22% indicated that the topic does not make any difference. The corresponding numbers for Group B are 50% - similar project, 43% - makes no difference and 7% - felt that would be more confident managing a different project.

Table 3. Mean responses from survey questions 8 and 9. Group A.

No.	Question	Similar project	Makes no difference	Different project
8	Please indicate whether you would have more **confidence** managing a project that is technically similar to or different from those you have participated in the past.	78%	22%	0%
9	Please indicate whether you would have more **capability** managing a project that is technically similar to or different from those you have participated in the past.	70%	30%	0%

Table 4. Mean responses from survey questions 8 and 9. Group B.

No.	Question	Similar project	Makes no difference	Different project
8	Please indicate whether you would have more **confidence** managing a project that is technically similar to or different from those you have participated in the past.	50%	43%	7%
9	Please indicate whether you would have more **capability** managing a project that is technically similar to or different from those you have participated in the past.	71%	29%	0%

Question 10 asked the students to rank the main strengths and weaknesses of their managers when they did their second year project. 30 valid responses were collected for the first part (strengths) of this question and 27 valid responses to the second part (weaknesses). The results are summarised in Figures 1 and 2 for all students. Because of the smaller number of valid responses, the survey data for Questions 10 and 11 was analysed in terms of the entire cohort. The data is given in actual number of student responses per category rather than percentages. The top three strengths, which the current fourth year students identified in their predecessors were: face-to-face communication (73%), general technical knowledge (67%) and personnel management (50%). The numbers given in the parentheses indicate the percentage of all responses, which ranked the specific skill in the top 3. The top three weaknesses were: electronic communication (56%), project specific technical knowledge (52%) and personnel management (44%).

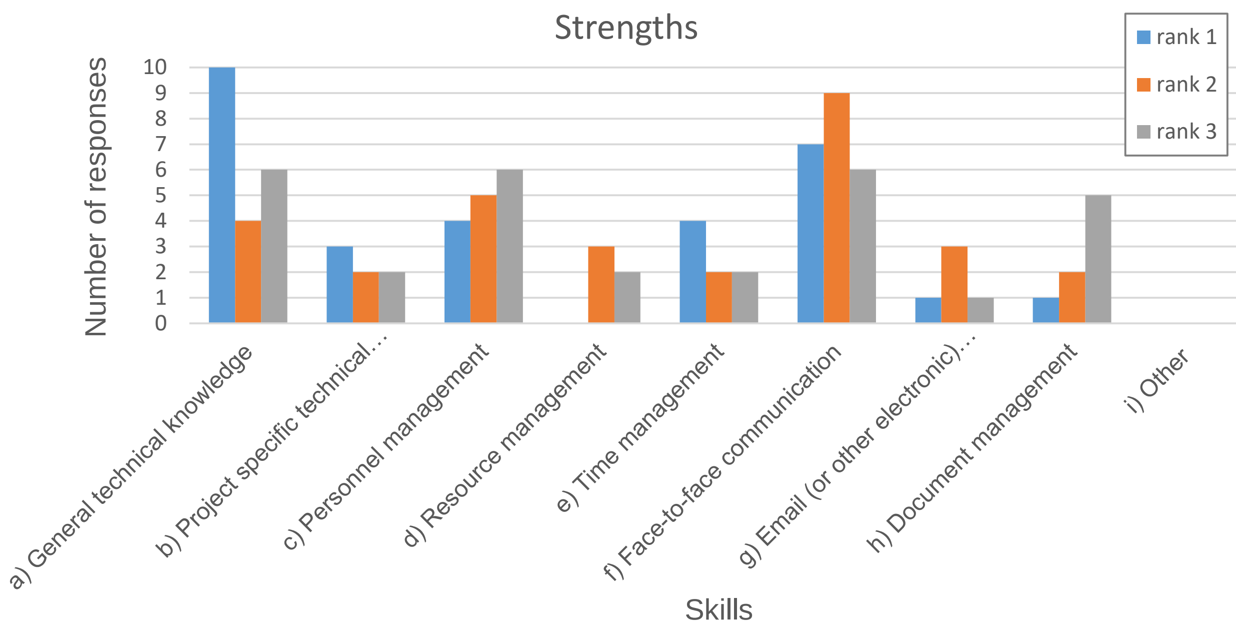

Figure 1. Summary of responses to survey question 10: In your opinion, what were the main strengths/weaknesses of the fourth year project managers when you did your second year project? Please rank the top three.

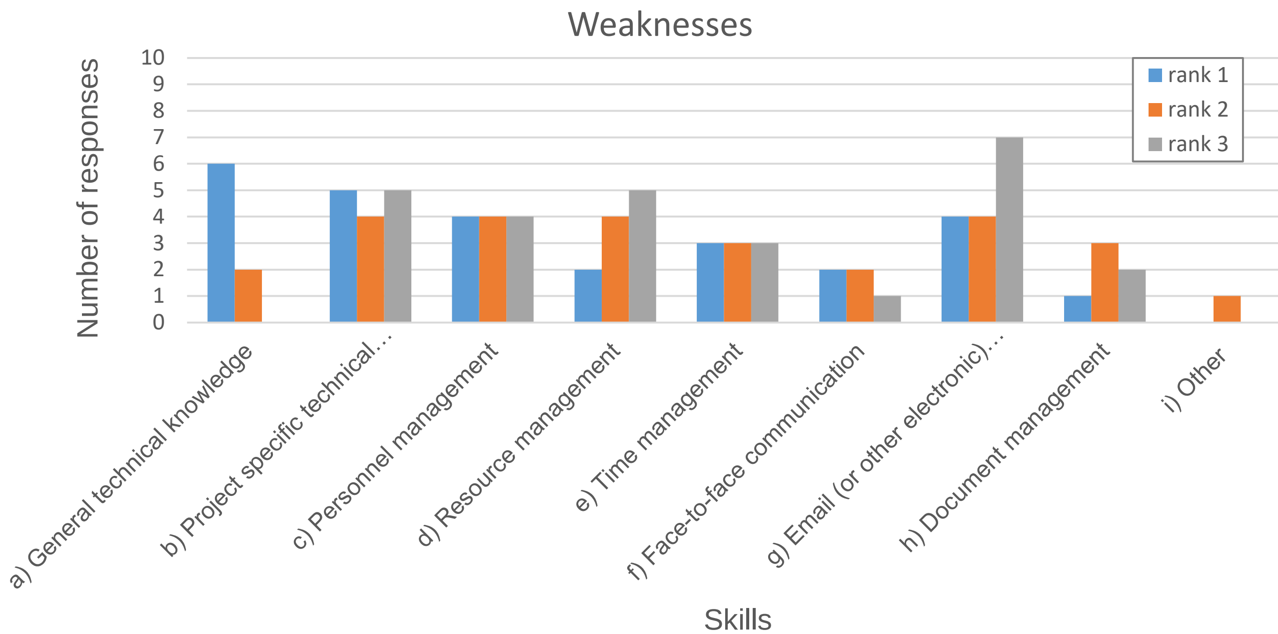

Figure 2. Summary of responses to survey question 10: In your opinion, what were the main strengths/weaknesses of the fourth year project managers when you did your second year project? Please rank the top three.

Question 11 probed students' perceptions about the most important skills a project manager should possess and what they consider to be their own greatest strength. The results are summarised in Figures 3 and 4. The number of valid responses in both parts of the question was 31. The students regarded personnel management as the most important skill. 94% of all responses identified this skill as important and ranked in the top 3. As equally important skills were highlighted: general technical knowledge, time management and the face-to-face communications. Similar results were observed for the students considering their own strength. However, in this case, 39% of the responses identified project specific technical knowledge to be their own strength.

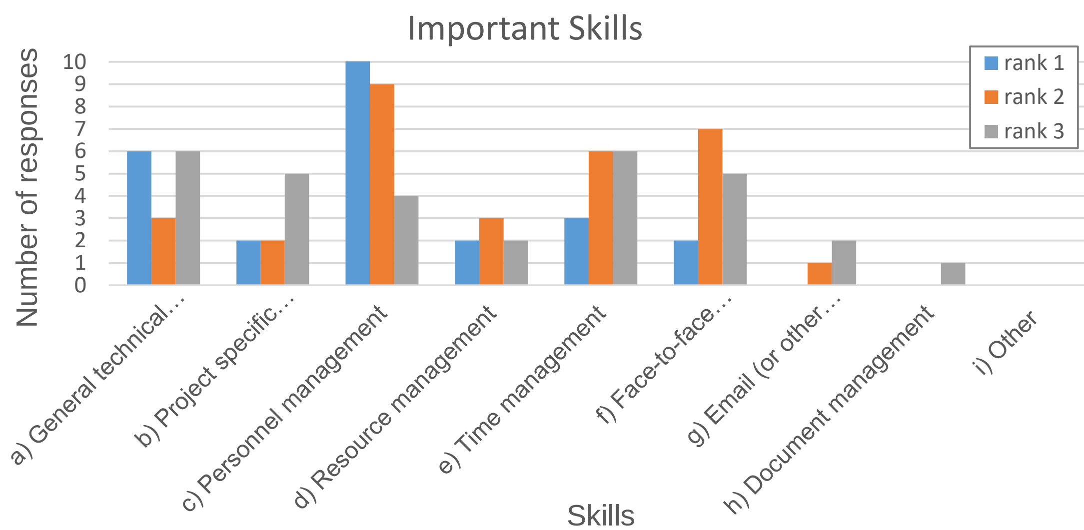

Figure 3. Summary of responses to survey question 11: In your opinion, what are the most important skills for a project manager to possess and what are your own greatest strengths as a project manager? Please rank the top three.

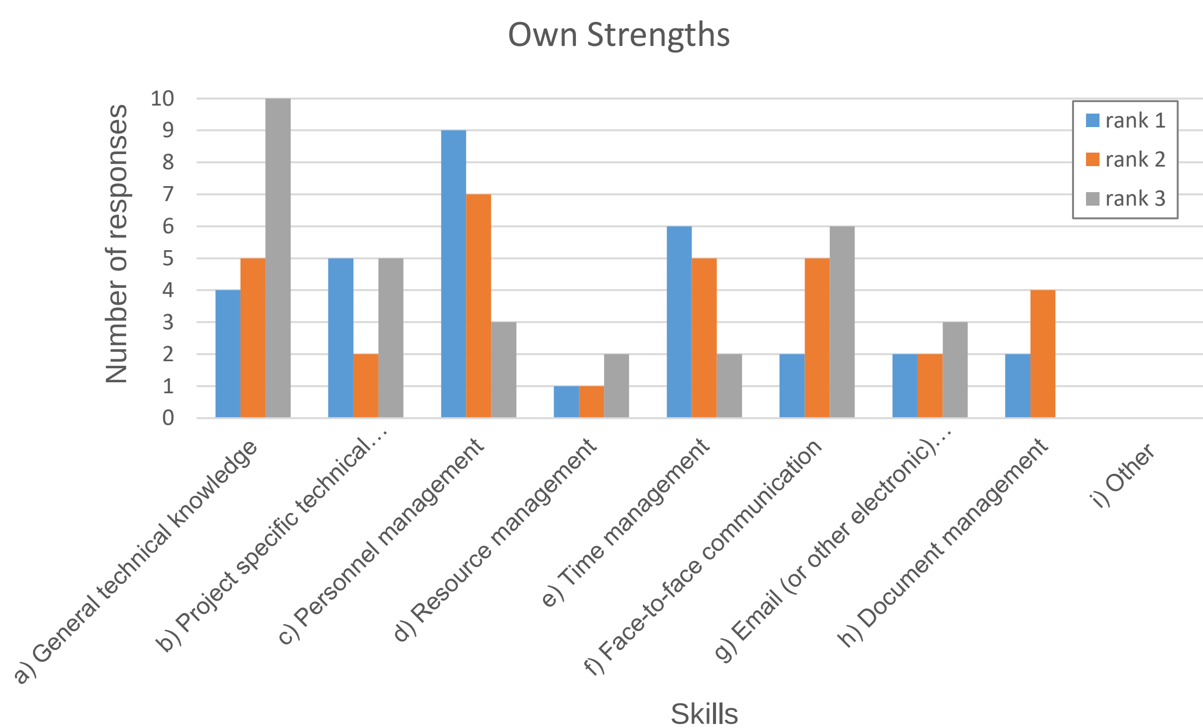

Figure 4. Summary of responses to survey question 11: In your opinion, what are the most important skills for a project manager to possess and what are your own greatest strengths as a project manager? Please rank the top three.

DISCUSSION

The results shown in Table 1 show no significant difference in the self-assessed confidence between Groups A and B, i.e. all students are almost equally confident about managing the current project. Group B indicated slightly higher confidence in both managing the project and providing technical guidance. However the difference is small and it is difficult to justify statistical significance of the results because the two groups are of different sizes (Group A is almost twice as large as Group B). The slightly higher levels of confidence could also be explained by the fact that Group B students had industrial placement experience, which seems to compensate for the lack of project specific technical knowledge that students in Group A would have.

The data given in Table 3 reveal that the majority (78%) of the students in Group A felt more confident and hence preferred managing a project where they possessed relevant technical knowledge. In comparison the students from Group B, who had done a different design project as second year students but had industrial experience seemed to draw their confidence from that experience and considered themselves sufficiently confident to manage any project. However the perceived capability to manage a project is exactly the same between the two groups, with 70% of the students preferring a similar project to what they had done in the past. It appears that industrial experience does not improve students' self-assessed capability to manage a different project, however it significantly improves their confidence.

Another objective of the survey was to gauge the understanding of fourth year managers of what they consider to be important skills that a manager should possess. Question 9 also helps to gauge what they felt was lacking in the managers of their design team when they were second year design students. Of the 27 valid responses, 14% regarded that none of the weaknesses in their predecessors were important skills. 60% thought that one of the skills that their manager lacked was important and the remaining 26% thought that their managers lacked two of the important skills that they should have had. Interestingly, none of them thought that their managers lacked all three skills they consider to be most important. Of the 86% who thought that their managers lacked at least one important skill, only 11% considered the lacking skill to be most important.

Another interesting outcome of the survey was the fourth year students' perception of themselves in terms of possessing managerial skills that they consider to be important. Of the 31 valid responses, 42% felt that they have one of the skills that they consider to be important as an own strength. Another 42% perceived themselves to have two of the important skills and 13% believed they had all three most important skills that a manager should possess. Only one student's response indicated a lack of any of the top three most important skills as perceived by the respondent. Interestingly, 23% of the respondents considered themselves as having the most important skill that they believe a manager should possess. And overall, an overwhelming, 97% of the responses indicated that they consider themselves as having at least one of the skills that they perceive to be most important in a project manager. This finds a reflection in their confidence of managing the project, as is evidenced by the overall success rate for managing projects that they had already participated in.

CONCLUSIONS

As mentioned earlier, there was a change from one in 24 groups producing a fully functional prototype when the design project managers did not have project specific technical knowledge, to only one in 24 not being able to produce it, when the design project managers had that knowledge. Considering the proportion of working projects designed to specification as an indicator of success, it is quite evident that the second case is far more successful. On probing the fourth year managers regarding their perception of confidence and capability with respect to the project, they responded with a clear preference for managing a project that they have specific technical knowledge about. Also, one of the top two weaknesses they identified with their project managers, when they were members of the design team, was the lack of project specific technical knowledge.

This was the first time that the managers were surveyed in this module for their perception of confidence and capability. Some of the factors that drive this perception have been identified on the basis of what they consider to be as important strengths, weaknesses and skills for a manager. Personnel management, face-to-face communication, general technical knowledge, electronic communication and project specific technical knowledge have been identified by the fourth year students as important factors that drive their self-confidence and perceived capability of managing a project.

Based on this survey, thought was given to adjust the module and provide feedback to the managers regarding how to bolster the key factors identified and use them to their advantage.

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BIOGRAPHICAL INFORMATION

Nikola Chalashkanov is a Teaching Fellow in the Department of Engineering, University of Leicester, UK. He is CDIO leader for the University of Leicester and coordinator for the 4th year Design Project Management module. He is a fellow of the Higher Education Academy and a member of the Institute of Physics (IoP) and IEEE.

Avinash Bhangaonkar is a Teaching Fellow in the Department of Engineering, University of Leicester, UK. He is an academic staff member associated with the Design Project module.

Rob Thornton is a Lecturer in Mechanics of Materials, Chartered Engineer, Member of the Institution of Mechanical Engineers (IMechE) and Fellow of the Higher Education Academy. Rob coordinates the 2nd year Integrated Engineering Design module in the Department of Engineering at Leicester.

Corresponding author

Dr. Nikola M. Chalashkanov
University of Leicester
University Road, LE1 7RH
Leicester, UK
nc137@le.ac.uk

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THE APPLICATION OF CDIO STANDARDS TO CLINICAL ENGINEERING EDUCATION

Yoshiyuki SHIMIZU

Department of Medical Informatics, Hokkaido Information University

Simon THOLLAR

Department of Systems and Informatics, Hokkaido Information University

Yuichi ANADA

Department of Business and Information Systems, Hokkaido Information University

Naohiko HAYATA

Department of Information Media, Hokkaido Information University

ABSTRACT

The task of clinical engineers is the operation, monitoring and maintenance of medical equipment in hospitals. Specifically, they are involved in cardiac and endoscopic surgery, cardiac catheter treatment, cardiac pacemakers, artificial respiration and blood purification therapy, and emergency medical care, amongst other tasks. Required skills involve, but are not limited to, communication skills, decision-making ability and expedient responsiveness.

The curriculum in the new clinical engineering department at Hokkaido Information University (HIU) consists of both medical education (including anatomy and pathology), and engineering education (including basic electrical engineering). Students are provided with an optimal workspace, appropriate medical simulations, and small-group education in an environment conducive to active learning. Hands-on training is conducted in a dedicated clinical engineering practice room, using appropriate medical equipment and/or simulations. The focus is not only on learning the correct response through simulating normal and abnormal situations, but also on how to develop problem solving skills, adopt a team approach, and acquire communication skills.

There is also an ongoing effort to develop an appropriate evaluation method and measure learning outcomes. Furthermore, it is recognized that an amalgam of basic education and practical training, forming an integrated curriculum, is fundamental to the design of the course. In addition, in order to fortify the students' integrated learning, extreme importance is attached to linking theoretical and practical exercises as well as establishing a collaborative system with clinical engineers working in hospitals. The application of the CDIO framework and associated standards to clinical engineering education seems both viable and valuable.

KEYWORDS

Clinical Engineers, Clinical Engineering Education, Practical training rooms, medical simulators, CDIO Standards: 2, 3, 6, 8

INTRODUCTION

Providing on-campus practical training using medical equipment for students enrolled in a clinical engineer training course has significant meaning as it allows an opportunity in a safe environment to learn fundamental equipment principles, operation and troubleshooting techniques. However, there is no binding rule concerning the content and extent, which is left largely to the discretion of each training institution. Methods and training systems vary depending on the school and it is difficult to verify that sound, systematic on-campus practical training is provided for all students (Suzuki, 2017).

This implies that such practical training potentially provides the opportunity for students to develop necessary skills while learning about equipment operation methodology in a clinical situation. As Itoh (2014) notes, social and communication skills of medical personnel are declining, and clinical engineers who work in medical care teams also need to improve such skills while still in training (Itoh, 2014).

In order to address these issues and ensure that skills are being appropriately learned, this paper investigates the feasibility of applying CDIO standards, fast becoming the global standard of engineering education, to clinical engineering education (Takemata, Minamide & Matsuishi, 2011). The main focus will be placed on practical training in the university, in addition to the design and consolidation of educational practice methods.

ROLE OF CLINICAL ENGINEERS IN JAPAN

The work of clinical engineers is defined by the Japanese CET (Clinical Engineer Technologist) Act as the "operation, management and maintenance of life support equipment" (Ishida, Hirose, Fujiwara, Tsuruta & Ikeda, 2014, 329). Such “life support equipment” or “life support systems” refer to devices whose purpose is to replace and/or assist part of the function of human respiration, circulation or metabolism (JACE, 2012). Specifically, examples include artificial heart-lung machines used in cardiac or cardiovascular surgery, artificial respirators that assist respiratory function, or artificial dialyzers which replacing kidney function. Clinical engineers also deal with many other additional medical treatment modalities and biometric devices.

With the qualification of clinical engineer not being introduced in Japan until 1987 (Komasawa, 2005, 50), and specific guidelines on work content being based on the "Clinical Engineer's Operational Guidelines", issued by the Health Policy Bureau, Ministry of Health and Welfare in September 1988 (JACE, 2012), it can be seen that almost 30 years have passed since national clinical engineer regulations came into effect. However, due to advances in medical technology, medical devices have diversified and become more sophisticated, and the role played by clinical engineers in medical care has moved to more of a multidisciplinary team approach. In October 2010, the Joint Clinical Engineering Committee, composed of the Japan Clinical Engineers Association and other professional societies, formulated the "Basic Clinical Engineer's Operational Guidelines - 2010" (JACE, 2012).

The revised guidelines categorize 11 tasks that fall within the ambit of the clinical engineer: respiratory treatment, heart-lung machine operation, blood purification, surgical area assistance, intensive care support, cardiovascular catheter treatment, hyperbaric oxygen therapy, monitoring and care of defibrillators, pacemaker and implantable defibrillators, and general medical device management. Work is further categorized temporally as pre-treatment, immediate, peri-treatment and post-treatment.

The guidelines further add that the "clinical engineer (should) be fully aware that the role of the specialized medical technician concerns the operation, maintenance and management of life support device(s)" (JACE, 2012), and that the "Clinical engineer closely cooperates with doctors and other medical personnel as a member of the medical team to constantly monitor the condition of the patient and to provide medical treatment that responds exactly to the needs of the patient" (JACE, 2012). This means that clinical engineers are not engineering experts who are only familiar with medical devices, but medical professionals who combine knowledge and skills of medicine and engineering, and are able to provide appropriate medical care to patients. It means that the clinical engineer is a member of a multidisciplinary medical team, with concrete tasks that need to be carried out skillfully and efficaciously.

CURRENT STATUS AND PROBLEMS IN CLINICAL ENGINEERING EDUCATION

Education related to the training of clinical engineers is stipulated by rules and regulations issued by the National Clinical Engineering Skills Training Center (JACE, 2012). As such, the curriculum, syllabus, learning contents, necessary facilities (such as classrooms, training rooms, and equipment), and other peripheral requirements are largely controlled.

In order to satisfy the requirements needed to sit the national examination for clinical engineers, the Ministry of Health, Labor and Welfare, stipulates that graduating students must have completed at least 101 credits in 25 designated subjects. Among them, students need to have obtained a basic understanding of the principles, structures, and configurations of medical devices used clinically in the field of medical device science, including the biological function of surrogate devices, the scientific theory of medical and biometric devices, medical device safety management, and the requisite practical knowledge and skills related to proper and safe usage and maintenance.

Appendix 2 of the Operational Guidelines (JACE, 2012) shows machinery and equipment that should be typically available to the training institution. Stipulated devices include a ventilator, an artificial heart-lung machine, an auxiliary circulation device, a hemodialysis machine, a pacemaker, a defibrillator, an electric scalpel, a patient information monitor and infusion pumps.

As such, both the name of the subjects that need to be included in the clinical engineering training courses, and the medical devices that should be accessible to the training facility are clearly specified. However, neither the teaching method for each subject, nor the content of a required hospital internship are specified, being left to the discretion of each training school, institution or host hospital.

Results from a questionnaire by the Japan Clinical Engineers Facility Council (Suzuki, Kudo, Kotaka, Nakahata, Tsukao, Ikenaga, Nakajima, & Kimura, 2017) investigating educational practices concerning the teaching of skills related to life support devices yielded several interesting results and comments. One common theme referred to the effect of employment status of faculty members on teaching quality and experiential knowledge. As few full-time faculty seem to have had actual experience working as clinical engineering technicians, there is a possibility that adequate skills or information may not be correctly conveyed to students, especially before internships. A second issue concerns access to medical equipment for hands-on training. While most training institutions reported having heart-lung machines and various auxiliary circulation devices, access to other medical devices used by clinical engineers concerning circulatory therapy was seen to be remarkably low. This resulted in both a lack of on-campus practical training, and a deficit in experiencing various medical support devices. Still other institutions reported having problems with insufficient lecture time and text inconsistencies.

Prior research on the effect of clinical engineering practicums pointed out the importance of such experiential learning in terms of the attitude of students, the treatment of patients and the ability to communicate among medical professionals (Sasaki & Sato, 2012). Recently, the introduction of objective structured clinical examinations into clinical engineering education has been attempted at several universities (Aikawa, Watanabe, Sugawara, Shimizu & Yamamoto, 2016), which shows how clinical engineering education is evolving towards a professional multidisciplinary team approach.

STATUS AND CONTENT OF ON-CAMPUS PRACTICALS

Medical equipment operation and management

Since the major part of a clinical engineer's work is the operation and maintenance of medical devices, including life support equipment, learning and mastering basic operation skills is indispensable for every student. All students need to learn not only how medical devices function normally, but how they behave in crisis or abnormal situations. They also need to learn about the relative safety of such devices. Associated medical skills can only be developed through providing hands-on experience. This is especially the case with complex vital apparatus, such as heart-lung machines, ventilators and blood purification devices, and extreme importance is attached to students learning from the very basics to more difficult, applied situations. Correct safety procedures, maintenance principles and management of medical equipment is also best learned practically (See Figures 1 & 2)

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Figure 1: Operating Room

Figure 2: Human Simulator

Education and communication skills

In the "Clinical Practice Guidelines" prepared by the Japan Clinical Engineers Association in 2013 (JACE, 2013), a number of skills and qualities involving clinical practice are stressed as having extreme importance. They include: awareness of role in team, patient communication skills, medical safety measures, infection prevention procedures, and desirable traits as clinical engineers. As such, a broad approach is needed when trying to teach or augment skills generally required for medical staff. Things such as social skills and cooperativeness are just as essential as academic and technical skills, even in the preliminary stages of on-campus hands-on clinical training (Itoh, 2014).

CLINICAL ENGINEERING EDUCATION AT HOKKAIDO INFORMATION UNIVERSITY

Outline of clinical engineering education

Clinical engineering education at Hokkaido Information University (HIU) is a newly-introduced degree course. It currently consists of basic liberal arts subjects including foreign languages, mathematics and physics, and more specialized subjects related to medicine, medical information, and medical engineering. Of the latter group, in the practical subjects, students experience using various types of medical equipment in biomedical instrumentation exercises, biomedical equipment experiments, and an artificial organ practical. In addition to these practical courses, a lecture follows or precedes each practical. Students thereby gain basic theoretical knowledge in addition to experiencing practical training, which helps them in acquiring the necessary skills for a clinical engineer. Medical equipment handled in the practical training phases include a wide variety of devices such as heart-lung machines, ventilators, artificial dialysis machines, auxiliary circulation devices, electric scalpels, defibrillators, ultrasonic diagnostic devices, electrocardiographs, biological information monitors and infusion pumps. The hands-on phase is comprehensive, and learning experiences include complex tasks such as how to rapidly respond to a patient's changing state, in addition to more basic items such as powering on the devices, connecting peripheral parts or making rudimentary settings.

On-campus practical training courses

The basic policy in clinical engineering practice at HIU is to give students as much access as possible to practical medical technology by creating environments that approximate actual situations that are liable to be encountered in medical institutions. New, up-to-date medical equipment and/or medical simulators are used to simulate various conditions that can occur in a clinical setting to help improve students' judgment and adaptive abilities. Emphasis is also placed on patient care and communication with other medical professionals, and exercises using either training dummies or more complex simulation mannequins, which respond according to their inbuilt sensors, are frequently used throughout the course. In the process, medical terms and procedures are appropriately introduced and learned.

Simulations in clinical engineering education

Medical simulation education, or hands-on experiential classes in a simulated environment using similar or identical equipment, has been widely used as an educational methodology with both medical practitioners and nurses, but its application in the clinical engineering field has been limited until recently.

A conspicuous difference between clinical engineering education and general engineering education is the presence and role of patients. While it is legally and ethically impossible for unqualified students to actively participate in the treatment of patients at medical institutions to learn and develop related practical skills, this can be remedied to some extent by effective simulation education, which allows students to learn in a safe environment using various medical simulators. This ensures the progress of the learner without compromising the patient, allowing both safe repetition and non-threatening failure. In the case of HIU, newly developed clinical engineering practice rooms serve as a clinical simulation center and allow various types of practical clinical engineering education to be carried out using medical simulators in a safe environment.

THE APPLICATION OF CDIO STANDARDS TO CLINICAL ENGINEERING EDUCATION

The application of CDIO standards to clinical engineering education represents a new approach to considering how clinical engineering may best be taught. As it is necessary to provide clinical engineering students with both the necessary theoretical abilities to successfully pursue their work, (skills related to medical knowledge and equipment, adaptability to situations, decision making ability) and human relations skills (teamwork, leadership, communication skills, ability to cooperate), the CDIO framework seems to offer an appropriate way to further advance education goals and skills in clinical engineering education (Takemata et al., 2011).

Standard 2 - Learning Outcomes

Clinical engineering faculty at HIU make a conscious effort to ensure effective practice by doing exactly what Crawley, Malmqvist, Östlund, Brodeur & Edström (2014, 51) recommend, setting “specific, detailed learning outcomes for personal and interpersonal skills, . . . (encouraging) product, process and system building skills, . . . (and ensuring) disciplinary knowledge, consistent with program goals”. This is shown below in Table 1, where targeted competencies in clinical engineering education are listed. The goal of each specialized subject is set according to the competency. Mastery of necessary clinical engineering skills is achieved not just by learning basic medical device operation, but by extending students to consider how settings may need to be changed to adapt to a patient’s situation or treatment needs. Communication with patients and other stakeholders is also vital to ensure meeting goals. Furthermore, as medical technology is constantly progressing, setting goals and evaluating learning outcomes in conjunction with a practicing clinical engineer will also help ensure validation of the program.

Table 1. Clinical engineering education competencies

Students should be able to apply basic medical knowledge and clinical knowledge stipulated as being necessary for clinical engineers.
Students are expected to be able to understand basic engineering skills necessary for clinical engineers and practically implement safe operation, management and maintenance of life support equipment and related treatment devices. They are also expected to be able to perform biometric measurement and have a sound understanding of medical information technology.
Students will need to have knowledge concerning the management process at medical institutions and an understanding of basic nutrition necessary for maintaining a patient's health. Communication skills will include the ability to convey information to, and obtain information from both patients and other members of the medical care team that the engineer may be working with.

Standard 3 - Integrated Curriculum

The content of the curriculum in clinical engineering courses is set and controlled by a government-advised nationally accredited body. For that reason, there is minimal flexibility in what is taught. There is, however, flexibility in how it is taught. It is important to design and implement a practical education curriculum where medical treatment equipment exercises and hands-on practicums are emphasized and linked to regular classroom theory. In addition, learning from practicing clinical engineers and undergoing off-campus clinical practice in a controlled environment at a hospital, implemented as a follow-up to on-campus programs, will lead to a more effective education.

Standard 6 - Engineering Workspaces

The clinical engineering practice room at HIU simulates an actual hospital environment. Most devices that a clinical engineer would control at a large hospital are provided, some being the genuine article, others simulations or working models. Students learn how to operation the various medical devices in a simulated environment, where either a sensor-fitted smart medical dummy or simulated program enables the students to feel real pressure as they would when working in an actual clinical environment. Table 2 shows medical devices and medical simulators available for hands-on use in the clinical engineering practice rooms.

The practical training rooms are divided into zones, related to the area being studied. In the emergency zone, students learn about such things as cardiopulmonary resuscitation for cardiopulmonary arrest patients, and how to interpret the various monitored data. In the intensive care zone, ventilator usage, information monitoring and emergency responses are covered. In the operating room zone, students take part in an artificial heart-lung simulation to learn how to operate a heart-lung machine during cardiac surgery. Each zone is relevant to a specified need, and students are motivated to learn by doing so in a realistic (but safe) setting.

Table 2. Medical devices and simulators in the clinical engineering practice rooms

Zone	Equipment	Zone	Equipment
Emergency Room	Multifunctional Human Simulator	Operating Room	Artificial heart-lung Machine
	Automated External Defibrillator		Cardioplegia Machine
	Defibrillator		Electric Scalpel
Intensive Care Room	Ventilator		Extra-corporeal Circulation Simulator
	Non-invasive Ventilator	Hemodialysis Room	Hemodialysis Machine
	Cardiopulmonary Support System	Cardiac Catheter Room	Coronary Intervention Simulator
	Intra-aortic Balloon Pumping	Clinical Examination Room	Electrocardiogram
	Vital Sign Monitor		Ultrasonography
	Infusion Pump		Thermography
	Pulse Oximeter		Laser Doppler Flow meter

Standard 8 - Active Learning

In clinical engineering practice, it is necessary for all students to repeatedly operate and practice using medical equipment. To maximize access to resources, it is also desirable to hold practical sessions in small groups. To this end, the clinical engineering practice rooms at HIU are designed to enable small group education. In addition, in order to deepen students' understanding, lesson design focuses on short lectures and ample opportunities to practice with the appropriate medical devices. By presenting various clinical scenarios and situations, students improve their ability to accurately assess and act upon a situation in an appropriate manner. The clinical engineering practice room is open at all times.

CONCLUSION

The goals of CDIO are to educate students who are able to master a deeper working knowledge of technical fundamentals, lead in the creation of new products, processes and systems, and understand the importance and strategic impact of research and technological development on society (Crawley et al., 2014, 13). These goals are very similar to the aims of the clinical engineering course at HIU, where the object is to graduate technically-able, knowledgeable students who are technologically savvy and eager to continue learning.

The CDIO approach provides the Clinical Engineering Department at HIU with an educational framework that better ensures that students learn necessary skills by establishing an appropriate process for systematic practice, consolidating an integrated curriculum, and allowing the improvement and evaluation of on-campus training. Despite being developed for engineering in general, CDIO standards appear to be suitable for application to clinical engineering education.

The essence of clinical engineering education involves acquiring a complex set of skills from an integrated curriculum, where students acquire hands-on medical equipment operation competency, based on a sound academic knowledge of medicine and engineering. A well-designed blend of classroom lectures and practical training is indispensable to this end.

Practical training focuses not only on standard procedures concerning the operation of medical devices, but also strategies on how to respond to abnormalities of patients and/or medical devices. Skills needed to make prompt decisions and problem solving strategies are also learned through prudent use of various medical simulators.

Also, as medical technology is continually progressing, the educational content and curriculum need to be constantly reviewed, and learning outcomes should be evaluated in terms of the original goals set. To that end, advice from practicing clinical engineers is indispensable, and coordination between medical and educational institutions is paramount.

While clinical engineering is possibly outside the original scope of education initially envisaged by CDIO, application of a number of the standards has been shown to be useful and appropriate in developing and unifying clinical engineering education. It is hoped that the framework can be further applied to improve the quality of education and ensure that future clinical engineers are equipped with the skills necessary for their work.

Final Thought

It is important to note that the CDIO framework has not been applied to clinical engineering education before, and represents a new approach. CDIO formalizes a number of practices, procedures and methodologies that have been loosely used throughout the university in various departments. Adoption of the framework is still very new, as is the clinical engineering program itself. To objectively evaluate the effectiveness of on-campus practical training, in addition to acquired skills and knowledge of students who learn under this framework, it may be beneficial to both monitor pass rates of national certification exams as well as develop an open communication network with hospitals, medical care facilities and other places of employment.
At this stage, it is difficult to document wins or difficulties, failures or successes for the simple reason that the program is still in its infancy. To fully evaluate how well outcomes are reached, further research is needed, and the clinical engineering program needs to be allowed to progress for a few years. The latter is especially important as the program is only in its second year, and no students have yet graduated. The authors look forward to following this up at a latter stage.

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BIOGRAPHICAL INFORMATION

Yoshiyuki SHIMIZU is an Associate Professor in the Department of Medical Informatics at the Hokkaido Information University. He is a clinical engineer in Japan, focusing on the general role of clinical engineering within biomedical engineering.

Simon Thollar is a Professor in the Faculty of Business Administration & Information Science at Hokkaido Information University. His research interests include e-learning, active learning, student & teacher motivation, and student engagement in classroom activities.

Yuichi Anada is a Professor in Department of Business and Information Systems at Hokkaido Information University, Japan. He graduated with a Bachelor, a Master and a Doctor in Applied Physics from Hokkaido University, Japan.

Naohiko Hayata *Ph.D.* is currently a Professor at the Department of Information Media, Hokkaido Information University, Japan. He is an original member of HIU-RMUTT international collaboration projects. His academic field is Environment-Behavior Studies.

Corresponding author

Yoshiyuki, SHIMIZU
Hokkaido Information University
Nishi nopporo 59-2, Ebetsu, Hokkaido, JAPAN
0698585
81-11-385-8427
shimizu@do-johodai.ac.jp

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CARD MODEL IMPLEMENTATION AT TDMU ALIGNED WITH CDIO STANDARD 8

[1]Tham Thi Hong Vo, [2]Anh Nguyen Quynh Phan

[1]Faculty of Engineering and Technology, [2]Website Editorial Board
Thu Dau Mot University, Binh Duong, Vietnam

ABSTRACT

According to CDIO, the main goal of teaching is to help learners achieve expected learning outcomes after completing their courses. To accomplish this goal and meet CDIO standard 8, it is very important for teaching and learning to be based on active learning approaches and for teachers to develop appropriate lesson plans. The more elaborate a lesson plan is and the more clearly-defined goal-related activities are, the more successful the teaching process will be. In this paper, we introduce a model for designing lesson plans called CARD, which has four steps including Context, Activity, Reflection, and Documentation. This model enables learners to use personal knowledge and experience to connect with and reflect on new content and thus promotes active learning, participation in learning activities as well as learner creativity by encouraging them to generate new ideas and create new products. Therefore, CARD is very significant for teachers to design and arrange learning activities to help learners achieve expected learning outcomes. With the real experience of applying CARD in teaching at Thu Dau Mot University (TDMU), Vietnam, in this paper, we present and analyze the strengths of CARD, explain why this model helps learners to easily attain the expected learning outcomes, and demonstrate that the model is appropriate for developing learners' creativity. Then, we illustrate with detailed examples to prove the effectiveness of the model in supporting CDIO standard 8.

KEYWORDS

CARD, Active Learning, Participation, Creativity, CDIO Standard 8.

INTRODUCTION

Vietnamese students in general and students in TDMU in particular study hard, work hard, and respect their teachers. However, a large number of these students are also limited by a lack of initiative in learning, a dependence on their teachers, and a lack of creativity. Learning by memorizing, imitating teachers and passive learning have been ingrained in them from primary school to high school. When starting college, many students cannot easily adapt to a new learning environment that requires a high degree of self-study and independence. In recent years, Vietnam's educational sector has proposed a wide range of solutions to transition from high school learning to university learning. Each school itself has its own solutions based on its own circumstances and students.

At TDMU, students come from many provinces in Vietnam with different learning styles, yet most of these students are quite passive in receiving new knowledge. To solve this problem, since its establishment in 2009, TDMU has focused on finding effective solutions, especially related to teaching methods for lecturers. TDMU has adopted a philosophy of education that includes "active, blended learning aligned with CDIO spirit", which the university has been pursuing since 2015. To this end, the university has promoted training programs that enhance its lecturers' capacity for learning design and instructional skills that align with CDIO. A large number of training programs have been launched since December 2015, including ISW (Teaching Skills), FDW (Facilitating Skills), ADW (Skills for Assessment), OnCDW (Design Online Course Skills) and OnISW (Online Teaching Skills). These training programs were developed to help lecturers create active learning environments, help students move from passive learning to active learning, and promote learner participation and creativity based on their individual experiences. In addition to these goals, in particular, stimulating the creativity and active participation of learners is extremely important to meet the CDIO philosophy. For this reason, TDMU continues to find and apply appropriate models, teaching methods, and evaluation tools to improve education quality (see model in Figure 1).

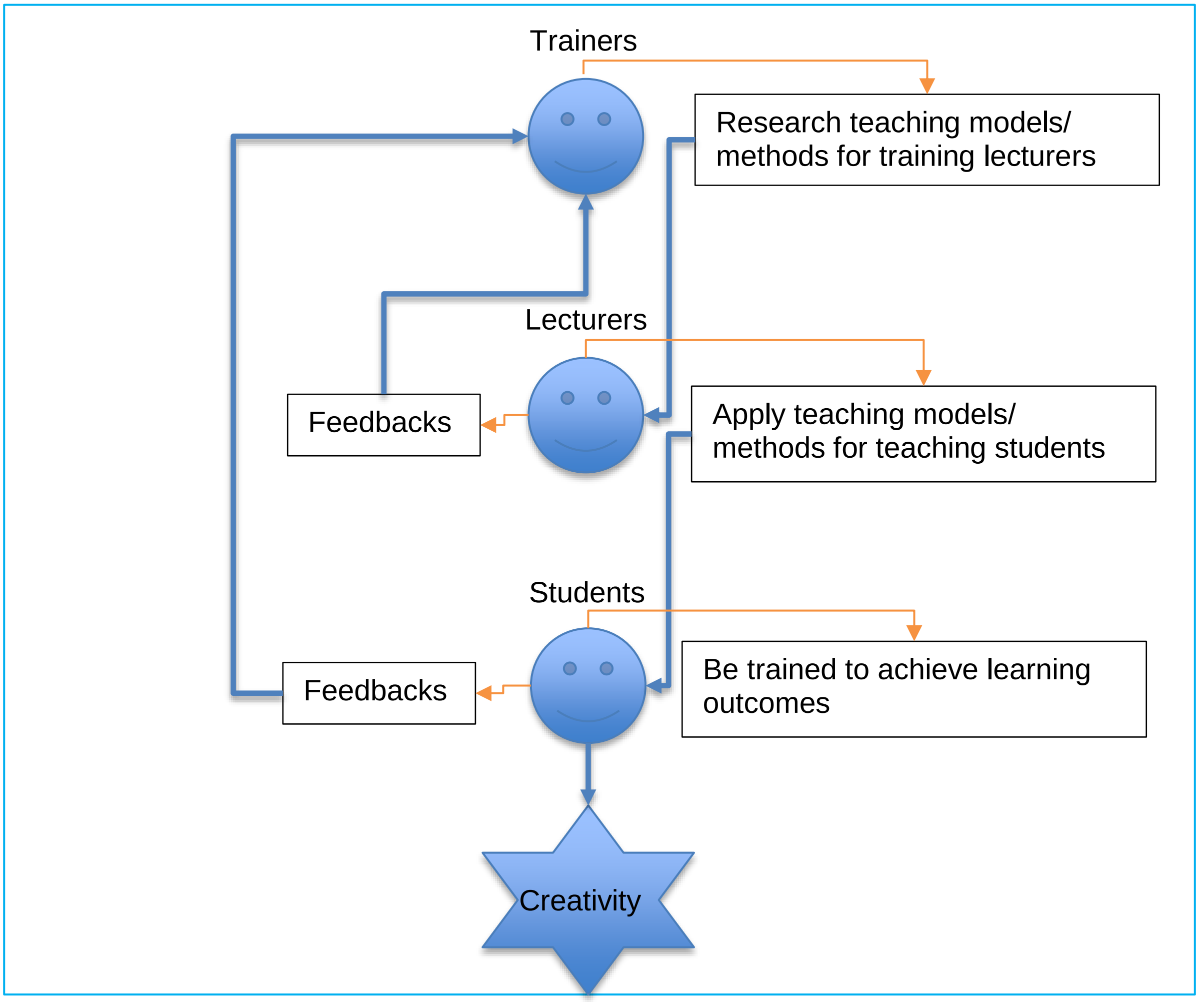

Figure 1. Enhancing teaching competency model in CDIO context at TDMU

To help teachers make good instructional activities for comprehensive and effective lessons, TDMU trainers share models, which have been tested and evaluated by experts. Based on the experiences of lecturers in applying active and blended classroom models and using lecturer and student surveys to support analysis, we would like to introduce CARD, one of the two models for designing lesson plans which are taught in ISW, a workshop that we will discuss in detail later, and are applying at TDMU. In this paper, we analyze the strengths and limitations of CARD based on a teacher and student survey. In addition, we also present a sample lesson plan used for teaching first year students in ours Information Systems department, faculty of Engineering and Technology. We would like to share our experience of using this model to enhance learner participation and creativity when we are a CDIO member and we expect to apply CDIO framework for improving education quality.

THE RELATIONSHIP OF ISW, CARD, AND CDIO STANDARD 8

Instructional Skills Workshop (ISW)

ISW is a program, based on a student-focused process. This program involves 24 hours of structured intensive instruction to enhance instructors' skills in planning, teaching, giving feedback and critical reflection. For over 30 years, it has been offering to more than 100 institutions worldwide as a method of facilitating the student-centered development and reflective instructors. Although it is designed for teaching adult learners (Day & Committee, 2005), an empirical research has been carried out to assess the impact on the faculties which have participated in the ISW (Macpherson, 2011). Research has typically shown that individuals who participate in this workshop agree that it is transformative to their teaching in the classroom (Macpherson, 2011). Another study tried to extend these findings by conducting a pre-post analysis of ISW and non-ISW participants. The goal of this research was to investigate the influence of ISW on developing a student-centered approach to teaching at university and college. ISW is also used for training professors teaching methodology (Fenrich & Johnson, 2016).

(Dawson et al., 2014) found that ISW participants were less teacher-focused, whereas the non-ISW participants showed no change in teacher-focus. This suggests that ISW had an effect on SW participants teaching behaviors' type. In addition, the research also found that participants frequently described replacing part of their lectures with a range of active learning methods, thereby reducing the instructional focus on transmission and implementing teaching methods known to boost deeper learning. ISW makes a shift towards increasing student focus in terms of thinking about what students' need, planning activities to engage students, and seeking student feedback.

CARD and ISW

Created by David Tickner, Vancouver Community College, including 4-main parts: C (Context); A (Activity); R (Reflection); and D (Documentation) (see figure 2), used for designing lesson plans CARD is one of the two main models, which are taught in ISW and, CARD suports teachers to enhance students' participation and creativity.

CARD and CDIO's Standard 8

(CDIO_Intiative) said that Standard 8 of CDIO is about Active Learning is known as using active experiential learning methods for teaching and learning. These methods engage students directly in critical thinking and problem-solving activities like manipulating, applying, analyzing, and evaluating ideas. Active learning in lecture-based courses can include methods such as partners and small-group discussions, demonstrations, debates, concept questions, and feedback from students. Active learning are considered experiential learning when students take on roles that simulate professional engineering practice such as design-implement projects, simulations, case studies, etc. By engaging students in thinking about concepts, new ideas, and require them to make an overt response, students not only learn more, they can recognize what and how they learn. Therefore, this process helps to enhance students' motivation, achieve expected program learning outcomes and form students' habits of lifelong learning. With active learning methods, students are able to make connections among key concepts and facilitate to guide the application of this knowledge to new settings.

(Crawley, Brodeur, & Soderholm, 2008) said that the theories of constructivism and social learning have been applied to a wide range of curriculum and instruction models and practices. The CDIO model focuses on a method called experiential learning, in which students take on roles that simulate professional practice in engineering. With experiential learning, students are engaged in problem-solving, critical thinking, and decision-making. These processes are relevant to personal and connected to academic expected learning outcomes. This approach requires teachers to create opportunities for students to question and combine ideas and skills through reflection, feedback and the application of the ideas and skills to new situations (Kolb, 2014).

CARD is a model designing based on constructivism theories, so lesson plans applying CARD are often in an inductive manner so that these lesson plans can maximize the existing knowledge of learners and enable learners to develop their creativity. Learners achieve expected learning outcomes through thinking, problem solving and working with others. Teachers are in charge of directing learners to the right topic, guiding them to reflect on, to draw lessons, or to present ideas following lesson plans. Teachers also provide additional scientific evidence.

The strength of CARD is that it helps learners achieve expected learning outcomes in a natural and easy way through empirical experience and reflection. Learners learn from their participation in activities with others, connecting with prior experience, and individual reflection process.

These above characteristics of CARD adapt to CDIO standard 8.

CARD IN DETAIL

Formally, CARD has 4 main steps as shown in figure 2, but in fact, there are 5 steps. The hidden step is "Determining expected learning outcomes", which is important when developing lesson plans using Bloom's taxonomy. Once the expected learning outcomes are clearly determined, the 4-steps as follows outline a simple and effectively strategy for conducting lesson plans.

- Context: Teachers can set the scene of the lesson by creating the lesson’s context to motivate and engage learners.

- Activity: Teachers can use several learner-centered teaching activities such as group work, discussion, acting, debating, etc. to give learners opportunities to express their views, knowledge as well as listen and acquire knowledge from others. This step has a direct effect on the next step, which promotes learners’ reflection and awareness, so they may create their own knowledge.

- Reflection: After a series of activities, lecturers create situations where learners have to think for themselves. Teachers can create a situation by asking questions or identifying problems for them to solve. When seeking answers or solutions, learners can learn the lesson on their own. This is a strength of CARD because it forces learners to express their opinions or attitudes, so teachers may be able to observe and evaluate student changes.

- Documentation: Teachers or learners can show documentation in this last step by. Teachers may use excerpts from experts to reinforce students' beliefs, or they may give learners a call-to-action. Teachers may recognize learners' attitude by observing their actions. Furthermore, it can be useful to let learners share what they have learned, or to encourage them to create products that describe their attitudes toward the issues, which have addressed in the lesson. However, when using CARD, teachers do not always need to evaluate the expected learning outcomes.

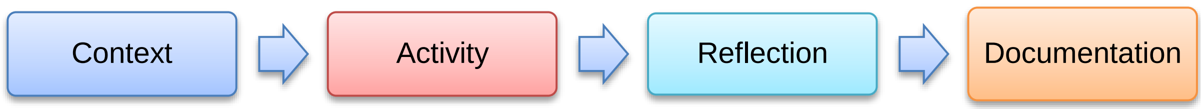

Figure 2. The 4 main steps of CARD

A SAMPLE LESSON PLAN USING CARD

In this section, we present a lesson plan that applies CARD to achieve the expected learning outcome of "Being aware of coding style and the importance of writing code in a correct format, a clear structure, and an easy to read manner". (See Table 1).

Table 1. Lesson plan, topic "Should we write nice codes?"

Step	Description	Time (min)
C	**Context** - Teacher shows some pictures about correct and incorrect format codes - Teacher ask learners to guess the topic - Quick Survey: Teacher asks learners to describe the way they write codes	5
A	**Group games** - Teacher asks each person to write down a small piece of code on a paper and his/her name on the back of the paper - Teacher collects their papers - Teacher sticks the papers on the board and randomly ask learners one by one to read the codes in 30 seconds. A reader gets 0.5 points if he/she reads correctly and the author of this paper gets 1.0 point (teacher calls students from groups by turns) - The group with highest points win the game - Teacher selects some papers and asks learners to find out high quality codes	25
R	**Questions**: - Do your codes follow any format? - Why do you write like that? - What is the advantages/disadvantage of writing codes properly and readable? - Do you enjoy reading the right format codes? - According to you, should you write codes properly and readable?	12
D	**Documentation** - Prove by showing companies that pay higher salaries to candidates who write properly and readable codes - Prove the importance of writing good codes such as being easy to read and inherit - Ask the groups to create slogans or posters, which describe their attitude toward code writing. Ex: "Say no to unreadable codes"	8

It can be said that the 4 steps of CARD allow learners to approach, feel and draw their own conclusions as well as express their attitudes toward their code writing style.

CARD IMPLEMENTATION EVALUATION

In order to find out the advantages and disadvantages of CARD application at TDMU, we conducted a survey from a focused group of 95 lecturers who have been approaching and appying this model since early 2018. The aims of the survey were to gather feedback from lecturers focused on the strengths and limitations of CARD.

Furthermore, we also surveyed for feedback of students in Social Affairs and Development Center at TDMU. This center teaches students Social Skills such as team working, communication, problem solving, effective learning methods at university, critical thinking, etc. All courses belongs to this center are focused on active learning, and almost teachers are trained to use models, especially CARD.

Table 2 shows the general information of survey participants at TDMU. Participants come from different faculties, teaching different class size, having different teaching experience, etc. They have participated in ISW where they learned how to use CARD. However, in this research, we do not focus on these differences of the participants' majors.

Participants

The survey participants includes 95 lecturers come from different faculties. They are trainers, facilitators and lecturers (see table 2)

Surveys

Each lecturer completed a survey, which includes questions related to CARD such as "How often you use CARD? What do you recommend about CARD? Does CARD help you create student interaction and collaborative learning easily? Does CARD make students be more active? Could you apply CARD for various subjects? What do you think about the implementation of CARD? How about the time consuming of CARD compared to other models? Does it stimulate students' creativity? Does it increase students' participation?" etc.

Table 2. General information of survey participants

	Attribute	Participant Number	Percentage
Field	Natural	16	17%
	Human Society	35	37%
	Technology	18	19%
	Economy	17	18%
	Pedagogy	9	9%
Average Class Size	Less than 30	6	6%
	From 30 – 50	72	76%
	From 50 – 100	15	16%
	Over 100	2	2%
Seniority	Less than 5 years	33	35%
	5 - 10 years	42	44%
	10 - 20 years	18	19%
	Over 20 years	2	2%
CARD lesson plan usage number	Never	17	18%
	Less than 5	32	34%
	5-10	26	27%
	More than 10	20	21%

Results

Table 3 shows that the biggest advantage of CARD for lecturers is that they can interact easily with students (77.5% of participants agreed) because all 4-steps of CARD require students to actively participate in the class. While using CARD, teachers could avoid the phenomenon of "monologue", transmitting in one way - leading to passivity in teaching and learning, so learners were more active (75% of participants agreed that CARD helped learners be more active) as they must continuously participate in activities such as brainstorming, problem solving, working in groups, etc. In addition, learners could have reflection based on their prior knowledge and experience, discussing with their classmates, so they could acquire their own new knowledge.

The second advantage agreed by survey participants is that CARD is quite easy to apply in many subjects and topics (36.3% of participants agreed). Some lecturers who teach in the science and technology field thought it was difficult to help learners achieve the learning outcomes of attitude. Therefore, they often presented their views and tried to persuade students what they should and should not do. This method was quite boring, and it was difficult to know whether students met the learning outcomes or not. However, when using CARD, lecturers were able to organize their lessons in a lively manner, set clear learning outcomes so that they might be able to fully observe and evaluate these learning outcomes through the way students express their ideas or respond to the given situations.

In addition, with the 4 steps which are described clearly and guided in detail, CARD is also considered to help save time for preparing lesson plans (23.8% of participants agreed). With ISW, each participant needs to compose and deliver 3-small lectures during 3-consecutive learning days and they need to use CARD at least for one lesson. In fact, more than 60% of participants choose CARD for their 2-lesson plans because of the main reasons such as being easy to implement, saving time, and allowing lecturers to challenge themselves with learning outcomes of attitudes - something that lecturers are keen to do but they have not had the right tools so far until they attend ISW.

For learners, CARD stimulates creativity, maximizes individual thinking (76% of people agreed). Based on the constructivism theory, lesson plans applying CARD are often in inductive manner. With this structure, it supports learners to reflect their prior knowledge, helps them develop their creativity, so they can achieve expected learning outcomes on their own and by working with others. The teachers only have the role of giving learners to the right topics, putting them into the right contexts, directing them to reflect on, drawing lessons or presenting and providing additional scientific evidence.

Table 3. Advantages and disadvantages of using CARD for teachers and students

Description	Feedback about CARD	Percentage
Advantage for teachers	Simple steps, easy to use and time-saving for making lesson plans	31%
	Applicable to many different subjects / areas	35%
	Easy to measure expected learning outcomes	23%
	Can be used for high school students	12%
	Easily get the interaction of students	77%
Disadvantages for teachers	Complex design steps, tricky and time-consuming for making lesson plans	24%
	Applicable only to certain subjects	48%
	It is difficult to measure / control expected learning outcomes	29%
	Can only be used for small size classes	53%
	Difficult for teachers to persuade students	22%
Advantage for students	Stimulate learners' creativity	76%
	Exploit individual strengths and experiences of learners	57%
	Learners are more active when attending classes	72%
	Learners can create their own new knowledge	51%
	Learners change their perceptions and behaviors after finishing class	58%
Disadvantages for students	Does not help learners create new ways of thinking, new methods	5%
	Does not support individual strengths and experience of learners	8%
	Learners are passive when attending classes	7%
	Learners can hardly create new knowledge	14%
	Hard to evaluate learners perception or behaviors' changes after classes	49%

However, CARD also has certain limitations. Many lecturers say that the model can only be implemented for classes with sufficient number of students and it is difficult to apply for the big size classes with a large number of students (53% of participants said that). Furthermore, with a large number of activities, the interaction between teachers and students becomes more difficult to deliver in the narrow classrooms where tables and chairs are difficult to move. It is a big challenge for teachers to design right activities when applying the model. Another limitation is that it is hard for teachers to evaluate immediately the change in the learner's perceptions because attitude changing often needs time). These limitations are challenges for lecturers when they first use CARD. However, once being mastered, they are able to overcome these challenges.

Table 4 shows participant expectations of improving CARD. There was 47% of participants were engaged, so they wanted to join more training programs and 35% of participants wanted to visit other classes to learn from others. However, just 11% of participants were willing to invite others to visit their classes.

Table 4. Participant expectations of improving CARD

Participant expectation	Percentage
No expectation	11%
Visiting other lecturers' classes	35%
Being visited and commented by other lecturers	11%
Joining competitions on teaching skills	24%
Joining more training programs	47%

To collect participant opinions about CARD, a 5-point Likert Scale is used for participant agreement with some statements about CARD (see table 5). Participants were asked to respectively select from 1 point to 5 points which stand for strongly disagree, disagree, neither agree nor disagree, agree, and strongly agree. The average of participants' ratings for each statement was calculated. Most participants agreed with the advantages of CARD, for example, a practical model supports learners to be more active, engaged and cooperative (see table 5).

Table 5. Lecturers' opinion about CARD

Opinion	Point					Average
	1	2	3	4	5	
CARD is a practical model	1%	4%	25%	46%	24%	3.9
The biggest advantage of CARD is to help learners achieve learning outcomes of attitude	7%	32%	35%	22%	4%	2.8
My students are more motivated while learning with CARD	1%	3%	9%	51%	36%	4.2
My students show more opinions, personal experience while learning with CARD	8%	24%	39%	23%	6%	2.9
My students are very cooperative and excited while learning with CARD	1%	2%	24%	51%	22%	3.9
I acquire a lot of new knowledge, new perspectives from my students	1%	5%	25%	44%	25%	3.9
I will continue to apply CARD to my career	1%	9%	22%	46%	22%	3.8
I will recommend CARD to my colleagues	0%	4%	16%	61%	19%	3.9
I am willing to modify CARD for specific classes and subjects that I teach	0%	4%	26%	45%	25%	3.9

CONCLUSION

In this article, we introduce about CARD, highlight its advantages towards achieving learning outcomes of attitudes, creating new knowledge - reaching higher levels in Bloom's taxonomy. In addition, CARD is a simple, easy-to-use model that supports learners to achieve expected learning outcomes in a natural way. TDMU has been using this model and they have achieved significant results. Further, learners' feedback about this model is very positive. Survey from the TDMU Social Affairs and Development Center shows that students highly appreciate the dynamics, creativity of the classes (4.67/5 points). We believe that teachers can easily make lesson plans, select creative learning activities based on flexible use of this model in teaching to meet specific learning outcomes of various subjects. To improve education quality, TDMU follows CDIO philosophy. To adapt CDIO standards, especially standard 8, TDMU always aims to bring teachers appropriate teaching methods for enhancing students' active learning. However, we have not analyzed how the difference of participants' major affects their opinions about CARD. We have not clarified how CARD compares to and integrates with other well-known active learning methods, neither. We are going to keep carrying out our further research.

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BIOGRAPHICAL INFORMATION

Tham Thi Hong Vo is a PhD candidate at Lac Hong University, Deputy Head of Information Systems Department, Faculty of Engineering and Technology, Trainer of Institute for Strategic Development at TDMU, Binh Duong, Vietnam. Her current research focuses on data mining, information management, and developing teaching methodology training programs.

Anh Nguyen Quynh Phan is Head of Website Editorial Board, Trainer of Institute for Strategic Development at TDMU, Binh Duong, Vietnam. Her current research focuses on Vietnamese culture, social skills and teaching methods.

Corresponding author

Ms Tham Thi Hong Vo
Thu Dau Mot University
06 Tran Van On, Phu Hoa, Thu Dau Mot, Binh Duong, Vietnam
+84983711737
thamvth@tdmu.edu.vn

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A SYSTEMIC APPROACH IN AN ELECTRONICS ENGINEERING CURRICULUM

Alejandra Gonzalez, Diego Patino, Luisa Garcia, Lizeth Roldán

Departamento de electrónica, Pontificia Universidad Javeriana, Bogotá, Colombia

ABSTRACT

This article describes the process followed by the Electronics Engineering Program in order to redesign its program using a CDIO-based approach. The new structure of the curriculum in the program was conceived from the solving problem paradigm. In that sense, we are looking for a systemic perspective of learning to improve the application ability of the engineering students. It means the new curriculum searches that students will be able to analyze the context identifying the problems and from that point, developing different general skills and tools from the discipline to solve the problems. This is indeed, a curriculum with a top down fabric that agrees with a constructive alignment composed by three particular emphases, which come from the Colombian needs: Communications, controls and energy, digital systems and signal processing. In this context, the student will conceive, design, implement and operate complex engineering systems in these areas. The presented emphases are the final stage of a formation plan which begins understanding the physic phenomena and the different mathematical tools that simplify those phenomena through signal processing which in our case is a fundamental part of the curriculum. This is why our program has an intensive formation in signal processing since the first year. We strongly believe that an electronic engineer requires to understand how to process a signal in a digital or analogic way.

The first part of the article explains why a new program is necessary. Then, it is explained how the different competences are taken into account. After that, general structure of the curriculum is presented where each unit is described. Some preliminary results are given since this new curriculum is currently being implemented. The final part of the paper is devoted to conclude and identify the future work.

This is a novel approach in Colombia. The electronics program from our university is the first accredited program that implements the CDIO methodology in the country.

KEYWORDS

Competences, Standard 3, Electronic Engineering, units.

INTRODUCTION

Electronics studies the characteristics and properties of the fundamental elements with which electrical current can be manipulated (usually of low intensity) in multiple ways. It conceives systems that provide a solution to practical problems of the society, both in the industrial environment and in everyday life.

The experiments carried out by different scientists in the late nineteenth and early twentieth centuries in terms of electrical and electromagnetic phenomena were the bases for electronic engineering. In 1884, Thomas Alva Edison detected the phenomenon that would give rise to the first "electronic valve" called a diode. In 1907, Lee de Forest trying to perfect the telegraphic receivers added a grid between the cathode and the anode of a diode. This new element was called the triode and is the basis of modern electronics. By the end of the 50s of the twentieth century, the triode evolves in the transistor, which revolutionized electronics. The transistor is indeed the basic element for the integrated circuits. Those reasons caused the need of specific engineers throughout the world. Colombia, does not escape from this boom and by the year 1960, the Faculty of Electronic Engineering of La Pontificia Universidad Javeriana was created. The main objective of the new faculty was written as: "The training of professionals whose scientific and moral preparation will enable them to perform excellently the profession". The duration of the studies was five years just like today. Very important for the good start of the Faculty was the great collaboration given by industries like Philips, Siemens and Ericsson.

Since its creation, the Electronic Engineering Career has systematically worked on its continuous improvement through four reform processes. In the 70s, a curricular plan was designed that gave importance to the subjects of the discipline. In the 80s, fundamentals of physics and mathematics were strengthened, increasing the courses in basic sciences. This was carried out to respond to the demands of the engineering industry with a scientific formalism. At the beginning of this century, a third reform aimed at the flexibility of the curriculum and a 1/2 distribution was implemented (1 hour of face-to-face work time per 2 hours of independent work time). This was in tune with the Mission and the education project which were formulated in 1992.

Since electronic engineering has been evolving, the device approach has been changed to a completely systemic approach. Moreover, Colombia is not a technology producing country and when this is required, it can generally be imported from other countries that have sufficient resources for the development of specialized devices. These reasons require that the electronic engineering in the country turn to an aspect mainly towards applications and towards the development of algorithms, of course without leaving aside the basic concepts of the device. Responding to these needs and in convergence with the guidelines of the University, CDIO Initiative promoted the design of an integrated curriculum which has as its central axis the cycle of development of products, processes and systems (CDIO cycle) (Al-Atabi, M., 2013). Thus, it must integrate, in equal parts, the disciplinary knowledge of engineering, the demands of the social context, the electronic industry and non-disciplinary skills and abilities (Brodeur, B., 2005), (Crawley, E. F., 2007), (Fai, S.K., 2011), (Crawley, E., F., 2014). Indeed, the reform also searches to answer to questions and criticisms of engineering education in the Latin American context, where the lack of industry and the lack of technological generation affect various areas of national development. A new integrated curriculum is generated, with methodological proposals taking into account all of this. This challenges in similar to other cases such as the one presented in (Parashar, A. K., 2012). The new curriculum of the electronic engineering career at the Pontificia Universidad

Javeriana focuses on a systemic point of view and it is for this reason that the unit of signals becomes important. This unit is complemented with the area of both analog and digital circuits from the systemic point of view. In this new reform the four parts of CDIO initiative is taken into account: Disciplinary knowledge and reasoning, Personal and professional skills and attributes, Interpersonal skills: teamwork and communication, Conceiving, designing, implementing, and operating systems in the enterprise, societal, and environmental context. All of this applied to the electronics engineering.

This article is distributed as follows: Next section shows how was the process to integrate the non-disciplinary and the disciplinary competence. Then, the curriculum with its different units is presented. After, some preliminary results prove some of the advantages of the proposal and finally conclusions and future work are given.

INTEGRATING COMPETENCES

The formulation of the new curriculum was developed in several stages. First, professors of the Department of Electronics worked in the structural changes of both the curriculum and the teaching / learning methodology. The proposal reform not only modified the structure of the subjects but also the teaching paradigm, to one of active learning based on problem solving, projects, experiences and collaborative (Jamison, A., 2014). Secondly, the personal, interpersonal and CDIO cycles are grouped under the term "non-disciplinary competences" in the new plan, were chosen, formalized and weighted. This set of skills and abilities known as Syllabus CDIO had its respective process of reflection among professors, graduates and members of the industry. The result is an Electronics Engineering program with an adapted CDIO Syllabus that reflects the institutional character (Verhaevert, J., 2016). Competences can be seen in Table 1.

Table 1: List of non-disciplinary competences for the new curriculum of the Electronic Engineering career at the Pontificia Universidad Javeriana.

2.1 ANALYSIS AND SOLUTION OF ENGINEERING PROBLEMS
2.2 EXPERIMENTATION, DISCOVERY OF REALITY AND CONSTRUCTION OF KNOWLEDGE
2.3 SYSTEMIC THINKING
2.4 PERSONAL ATTITUDES AND SKILLS
2.5 PROFESSIONAL CAPABILITIES AND ATTITUDES
3.1 TEAMWORK
3.2 COMMUNICATION
3.3 COMMUNICATION IN FOREIGN LANGUAGES
4.1 SOCIAL AND EXTERNAL CONTEXT
4.2 BUSINESS AND BUSINESS CONTEXT
4.3 CONCEIVING AND APPLYING ENGINEERING TO SYSTEMS
4.4 DESIGN
4.5 IMPLEMENTATION
4.6 OPERATE

In third place, once the competences were established and the profile of the graduate was defined, the reflection and reformulation of the disciplinary contents was started. For this, backward design technique was used in order to obtain the subjects of the new curriculum (Brodeur, B., 2005), (Crawley, E., F., 2011).

Once the disciplinary contents have been determined, they are integrated into the adapted CDIO Syllabus. It identifies the learning sequences associated with each competence and content according to the expected development of each one and taking into account the different training moments. The results from this methodology is shown in the next section.

Development of content and competences depends on integrated active learning, in which students put into practice the skills of training through teaching / learning activities that promote disciplinary content. Active learning is based on activities where students simulate the professional practice of engineering. This requires them to apply, analyze and evaluate ideas. Moreover, they have to solve problems of the discipline since the first semester. In this way they understand the concepts and develop the skills of the training plan.

The following section describes the result obtained from this job of integrating competencies with the disciplinary skills.

THE NEW ELECTRONIC ENEGINEERING CURRICULUM

General description

As mentioned above, the new curricular structure of the Electronic Engineering program was developed as a result of a continuous reflection of the program, attending to the requirements of the actors of the context (industry, unions, graduates, students and teachers). A 5-year structure was created with courses in charge of developing the students' skills, knowledge and skills necessary for their professional practice (González, A., 2016).

This curricular structure, includes 51 articulated courses following the institutional policies and the disciplinary, integral and flexible guidelines of the program. It has a total of 160 academic credits. The component of the fundamental core represents 68% of the plan including the mathematics, physics, engineering, and institutional lines.17% of the academic credits are assigned to the emphasis of the discipline and 14% corresponds to subjects of free choice. Moreover, the new curriculum presents particular characteristics compatible with the guidelines of the context offered by the CDIO philosophy:

- Engineering introduction course in first semester, which is characterized as a primary design and construction experience.
- Courses in physics and mathematics aligned with the courses of the discipline that integrate general competences
- It starts disciplinary formation from first semester.
- Two additional design and construction experiences are given: one in the third year and one in the fifth year.
- Balanced academic load, related to the total number of courses.
- Innovative practices of teaching, assessment and work spaces.
- It has balance between the theoretical topics and practical ones.
- Rising relationship with industry.
- A program to promote the retention of students.
- Subjects of humanistic areas are connected from the discipline.

- Integrated training in skills different to disciplinary ones.

The Electronics Engineering curriculum was designed from a systemic perspective. In this sense, the disciplinary training begins uninterrupted from the first semester. It is approached from the construction of a background related to the cycle of identification and formulation of problems. In this context, solutions are technological and the object of design corresponds to an electronic system. From the first year of training, students are faced with knowing the context and their problems. They understand the responsibility they acquire as a professional. The solution of problems in the real world implies the development of a graduation profile with knowledge and technical skills. Moreover, a group of general competences are given that will allow the graduate to profess with excellence their discipline. A gradual learning of personal, interpersonal skills and CDIO determines the scope of each of the year. Integration of these competences requires a curricular design based on training results that combine technical and disciplinary skills as well as general competencies (communication, teamwork, etc.). At this point, the viability of an integrated curriculum is generated in the choice of some issues, which are really essential for the formation of the student, especially in the areas of mathematics, physics and engineering (Fai, S.K., 2011), (Jamison, A., 2014). These disciplinary concepts are called nuclear competences and allow the construction of integrated training results with general competencies. The course programs are characterized by including a group of training results, the activities associated with each objective and the learning assessment rubrics that feed the program evaluation model.

Disciplinary units

A general description of the curriculum can be approached from the general objective of the training of electronic engineers. As mentioned before, the goal of the program is to train professionals capable of delivering electronic solutions to the problems of the context. In this sense, the curriculum proposes six disciplinary work units that contain a group of courses dedicated to each specific area: physics, mathematics, signal processing, analog systems, digital systems and CDIO project unit. The distribution of lines is shown in Figure 1.

The Physics unit is responsible for developing the learning of physical phenomena, which form the context that an electronic engineer must know. These phenomena are the elements that will be measured, adapted, processed and returned to the world. The competences associated with these lines are related to the construction of knowledge, data analysis and work in the laboratory.

The way to capture the information of the world and return it to it, is carried out by electrical signals. Thus, this becomes the object of study of electronic engineering. That is why a unit of signals processing is developed. The signals represent physical phenomena, their nature in multivariate and complex. In this sense, the courses of the unit become a context to develop the skills of the cycle of identification and formulation of problems associated with the area of signals.

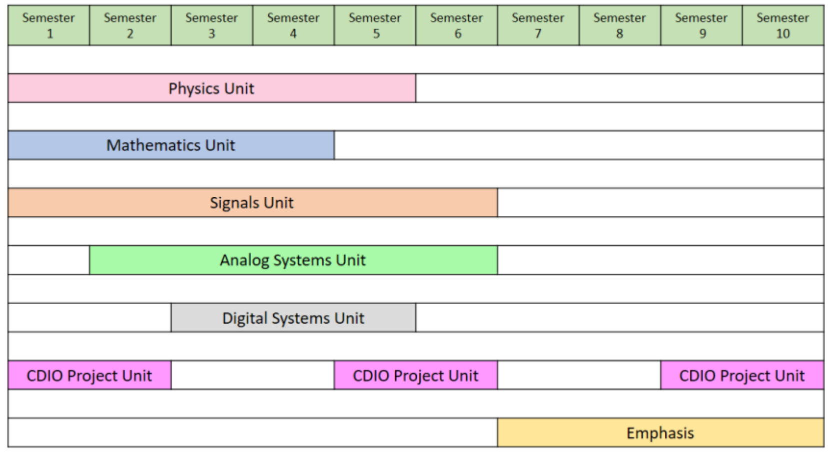

Figure 1: List of units for the new curriculum of the Electronic Engineering

The conditioning, processing and communication of signals requires technological tools that correspond to electronic systems. At this point the Analog Systems Unit provides circuit analysis tools and develops the understanding of the operation of analog electronic devices. The perspective of the courses is systemic and allows the development of holistic thinking as a tool for problem solving.

Digital systems unit provides training in digital processing tools and devices and hardware development for a particular solution. The competences developed are associated with the product construction cycle.

Finally, skills, knowledge and competences developed in those lines are integrated through the design and construction experiences belonging to the CDIO project unit. These are characterized as projects in the real context of the industry or the research groups of the engineering school. The projects integrate general skills such as teamwork, communication skills, project management and again expose the student to the CDIO cycle. The relationship between the different units and competences is shown in Figure 2. During the fourth year, students have the option of choosing an emphasis which comes from the Colombian needs: Communications, controls and energy, digital systems and signal processing. In this context, the student will conceive, design, implement and operate complex engineering systems in these areas.

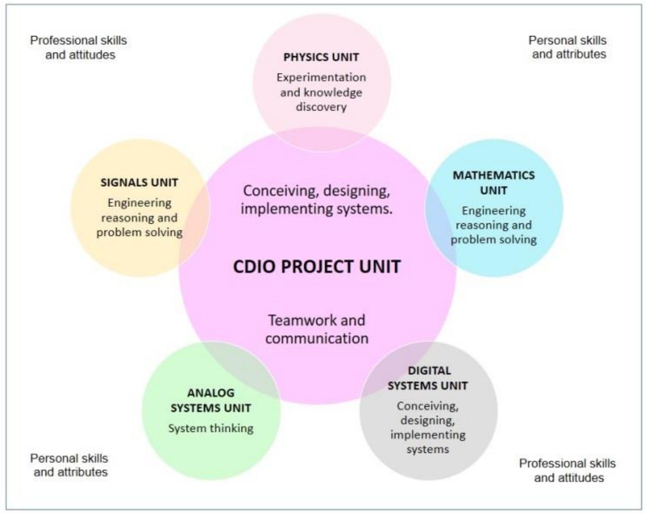

Figure 2: List of non-disciplinary competences with the units.

The curriculum is currently implemented until the 4th semester. Next section shows some results obtained in the implementation of this curriculum.

PRELIMINARY RESULTS

In order to measure the impact of the same in the learning of competences and contents, a survey was designed. Students could answer it voluntarily. 68 students responded from 231 active students in the new curriculum. This is 33% of the population. The questions were of the multiple choice type with 5 possible answers. This survey measures the quality of each one of the non-disciplinary competences developed within the program and the skills of the CDIO curriculum. The followings questions per competence (Analysis and problem solving, Experimentation, discovery of reality and construction of knowledge, Systemic thinking, Personal attitudes and skills, teamwork, communication, Design) were:

a) Do you think that the competence is developed in the program?
b) About quality, at what level is this competence developed?
There were also similar questions about basic abilities (Mathematics and Physics):
a) Do you think that the basic ability is developed in the program?
b) About quality, at what level is this basic ability developed?

Test 1: Non-disciplinary Competences

Table 2 shows the perception in percentage that students have about the non-disciplinary competences from table 1. Notice that not all the competences given in table 1 are analyzed. This is because some of them are introduced after third year (5th semester). About the competence "Analysis and problem solving" competition, 78% thinks that the quality with which this competence is developed is very high or high. 7% of the population thinks that it has an average quality, low or very low. Regarding the competence of experimentation, discovery of reality and construction of knowledge, the behavior is very similar. 74% has the opinion that the implementation of this competence in the CDIO classes of the Electronic Engineering Program of the Pontificia Universidad Javeriana is very high or high, 21%

considers that quality is average. Results for the systemic thinking competence show that students consider it high or very high quality obtaining and 56%. Only 8% considers that quality in this competence is low or very low and the rest of the population think that quality is average. In the case of the competence of attitudes and personal skills, 71% of the population believes that quality is very high or high, 22% considers that quality is average. Regarding competence of teamwork, 82% of the population considers that the quality of this competition is very high or high and 18% of the population remaining is distributed among medium, low or very low quality. The communication competence has a perception of very high or high quality among students of 60%. 35% considers communication competence to be average. For the design competence, 59% of students considers that it is high or very high quality in the courses of the program. Figure 3 shows the perception in number of students with respect to each disciplinary competences.

Table 2: Perception of students against the quality of competencies in percentage.

Competences	Very high	High	Average	Low	Very Low
2.1	19%	59%	19%	3%	0%
2.2	24%	50%	21%	3%	3%
2.3	13%	43%	35%	7%	1%
2.4	24%	47%	22%	4%	3%
3.1	51%	31%	10%	6%	1%
3.2	19%	41%	35%	1%	3%
4.4	25%	34%	34%	6%	1%

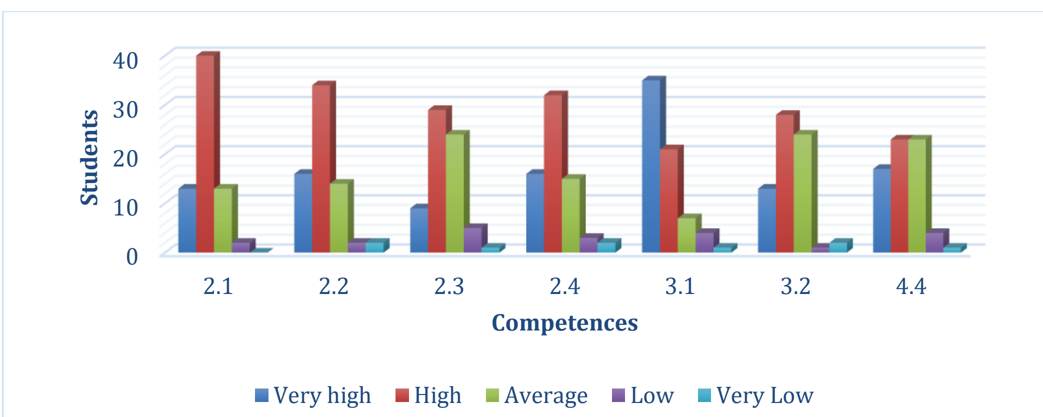

Figure 3: Perception of students regarding the quality of competencies in the number of students (See competences in table 1)

As it can be seen, the perception is in general very good. There is some improvement to be implemented mainly in the competences of Systematic Thinking, communication and design. One solution is a mentor program among others.

Test 2: Basic abilities

It was also measured the perception of the students in terms of two basic abilities: Mathematics and physics. For mathematics ability, 84% considers that the development of these skills is very high, high or average. Only 16% thinks that the quality is bad or very bad. Regarding the ability of physics, the students' perception is that 81% of this skill has very high, high or average in the development of the courses developed under the CDIO standards. These results are summarized in Table 3. Figure 4 shows this behavior with the number of students.

Table 3: Perception of students against the quality of skill development

Abilities	Very high	High	Average	Low	Very Low
Mathematics	25%	34%	25%	12%	4%
Physics	22%	44%	15%	13%	6%

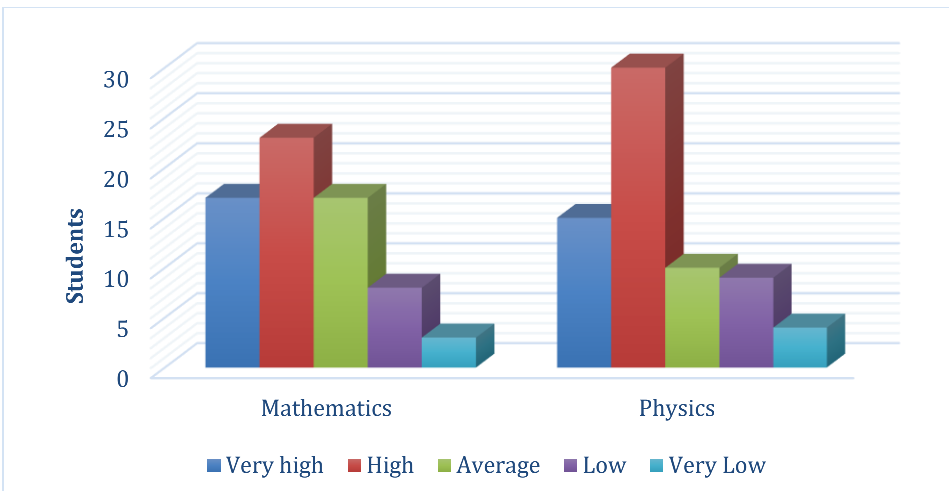

Figure 4: Perception of students against the quality of the development of skills in number of students.

From this test, it can be concluded that physics has a very good perception. This is due to the increase of contact hours in those courses. Mathematics need some improvements in order to rise up the quality.

Test 3: Academic states

A comparison is then made between the academic states of the students that are part of the old plan and the new CDIO plan. Both populations are different in size, and the behavior of both is very similar in terms of academic status and academic mortality. In the university, there is two warnings that the students receive. The first warning appears when the GPA is less than 3.4/5.0. A second warning appears if after being in first warning, the GPA continues to be in 3.4/5.0. Figure 5 summarizes the academic states of the students. As it can be seen, the exclusion in both cases is very similar. Exclusion is 3% for the new program. For the old program is 4%. 6% of students for the new program have second warning and for the old plan is only 2%. This is a point also to improve in the future work.

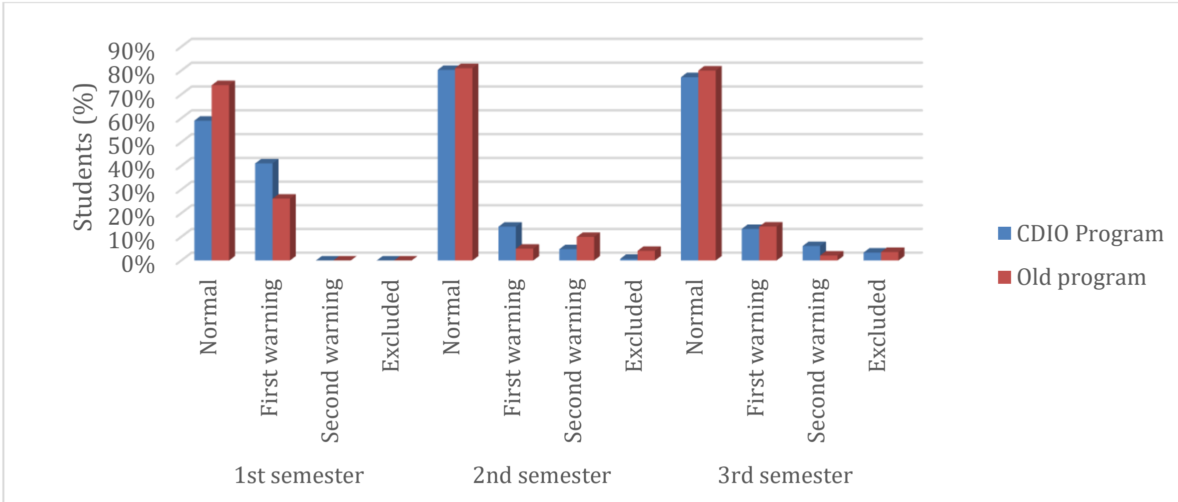

Figure 5: Comparison of academic states. CDIO Program and Old Program.

CONCLUSIONS

In this article, it was shown the process that we used in La Pontificia Universidad Javeriana to implement the CDIO methodology in Electronic Engineering. Indeed, this methodology is adapted to form the new program. The article showed how this adaptation was carried out by the professors. It also shows the units that were mapped with non-disciplinary competences. Perception of the students is in general positive. Some other measurement must be carried out. However, these results also show some challenges regarding particular competences. This program needs a continuous evaluation culture which allow to manage a continuous improvement leading to effective changes in the courses. These changes imply, among other elements, the reorientation of training results, rubrics and scope of the courses. For that reason, ABET will be used as evaluation model in the future. The performance of the students' needs also to be identified in order to give accompaniment to ensure student success. Regarding this point, a program was designed that includes mentoring strategies, reinforcement workshops in basic math and communication skills, among others.

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BIOGRAPHICAL INFORMATION

Alejandra Gonzalez, Ph.D is an Associate Professor in the Department of Electronics Engineering at the Pontificia Universidad Javeriana, Bogotá, Colombia. Alejandra's research interests include embedded systems, digital systems design, high-level systems design, artificial intelligence, robotic and curricular management.

Diego Patino received the Electronics Engineering degree from the National University of Colombia, Manizales-Colombia in 2002. Master degree in Automatic control and computers from the Andes University, Bogotá-Colombia, in 2005. Ph.D. degree in Automatic control and signal processing from the National Polytechnic Institute of Lorraine, Nancy, France in 2009. He is currently full time professor at La Pontificia Universidad Javeriana at Bogotá, Colombia and head of the electronics department.

Luisa Garcia is a is an electronics engineer with a Master's degree in the same area. She has worked in digital systems area in several Colombian universities, where she has developed methodologies for active learning in their classes. She is currently a student of the Doctorate in Social Sciences and Humanities of the Pontificia Universidad Javeriana. His areas of interest are digital systems design, active learning, cognitive sciences, and complex system design.

Lizeth Roldán is an electronic engineer from the Pontificia Universidad Javeriana she is a lecturer in the Electronics Engineering Department at Pontificia Universidad Javeriana. She also is an assistant to the electronic master program at the electronic department of Engineering

Corresponding author

Dr. Diego Patino
Pontificia Universidad Javeriana
Cra. 7 # 40 - 62
Bogotá, Colombia
+57 1 3208320 Ext. 5550
patino-d@javeriana.edu.co

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APPLYING KAIZEN IN A PROJECT-BASED LEARNING ENVIRONMENT

Katariina Tiura & Marika Säisä

ICT Unit, Faculty of Engineering and Business
Turku University of Applied Sciences, Finland

ABSTRACT

"Kaizen" is a lean manufacturing tool that is used to improve quality, productivity and culture in different environments. The idea of Kaizen is to apply small, daily changes that result in major improvement over time. Roughly translated to English, Kaizen means "good change" and it can be considered as a framework for continuous improvement.

This paper focuses on changes and possibilities of Kaizen in "theFIRMA" that is a project-based learning environment in Turku University of Applied Sciences, Finland. TheFIRMA operates like a real company that concentrates on ICT-related customer assignments and R&D projects. The mission of theFIRMA is to offer interesting project-based learning opportunities for the students as well as to create benefit to the customers when digitalizing their operations. Most of the customers are local small and medium-sized enterprises (SMEs).

The volume of the project portfolio of theFIRMA has grown significantly during the past few years. Accordingly, there has been a growth in the number of customers and students, which has increased complexity and caused challenges with resourcing and scheduling. In this paper, Kaizen is presented as one of the tools that can be used to develop the learning environment's operation towards more efficient and reliable state. The paper describes both the changes Kaizen has already produced in learning environment and possible future implementations.

KEYWORDS

Kaizen, R&D learning environment, CDIO, ICT, Project-based learning
Standards: 6 and 8

INTRODUCTION

"TheFIRMA" is a project-based learning environment, located in Turku University of Applied Sciences (TUAS) in Finland. TheFIRMA operates in the Information and Communications Technology (ICT) unit of TUAS and thus, concentrates mainly on ICT-related projects. TheFIRMA operates like a company, doing customer projects for local SMEs with students as its main personnel. Students work in the customer projects learning by doing and earning credits from their work. The goal is to build long-term customer relationships, where a satisfied customer is familiar with theFIRMA's way of working and students can provide solutions to the various needs.

Besides the student-run atmosphere suitable for the involving continuous improvement, theFIRMA has also the other key element for successful implementation of Kaizen: the actual need for small changes. When theFIRMA was founded by merging several learning environments together, best practices were naturally preserved. After founding the learning environment in 2015, there has been a major growth in both student and customer project amounts. This has brought up two main issues: resourcing and scheduling.

The Kaizen approach can be used to improve both employee (students of theFIRMA) and customer satisfaction. Kaizen philosophy states that all employees are active sources of improvement initiatives. Allowing students to make suggestions about their own working environment and processes, they are more likely to engage in theFIRMA's operation for a longer period of time. Reducing waste, or "muda", eliminating too complicated processes, or "mura" and avoid the overburdening, "muri", usually lead to more proficient project work. This reduces the number of mistakes and elevates the working atmosphere as well as customer satisfaction.

THEFIRMA'S OPERATION AND MANAGEMENT

TheFIRMA's projects mainly consist of web development, software requirement analysis, database design, digital marketing assignments and different testing activities. These assignments form a wide selection of challenges for students to develop their knowledge, skills and attitudes. Project tasks are completed in teams and more experienced students will act as project managers or senior team members and mentor the junior team members. Thus, everyone learns both working-life-relevant social skills and improves their technical knowledge.
Students are encouraged to be self-driven and active and so usually teachers are in consulting and mentoring role. The team carries the project from planning to end-user training, thus following the CDIO path in conceiving, designing, implementing and, in some cases, even operating.

Operations of theFIRMA are overseen by the personnel of TUAS. There are currently four members of staff who are responsible for theFIRMA's operations in strategic or operative level and have a part of their working time allocated to this purpose. In addition, other teachers participate in R&D projects as mentors. TUAS teachers, project managers and project engineers are ensuring that the projects get a good start with proper allocation of students, and from then on most of the responsibility is handed to student project managers.

The student project managers are responsible for ensuring that the projects meet their deadlines, that the customers know how the project is proceeding and that there are enough resources, especially students with right skill sets, available for the tasks. Student project managers report systematically about projects' progress to the staff members and to student CEO, who is head of theFIRMA's students. The student CEO has the knowledge about theFIRMA's financial and resource situation and he makes sure that the daily operations run smoothly. Together with the TUAS staff, student CEO and student project managers form theFIRMA's management team.

Currently there are four student project managers in theFIRMA, each of them managing several projects simultaneously. They are part-time employees of TUAS, as the idea is to award the most successful and hard-working students with responsibility and employment. In other words, while studying according to regular curricula and earning credits, student project managers are getting paid from their work in theFIRMA. Being responsible for customer communication, project planning and team leading provide the skills that are not usually available for the second or third year bachelor students through regular courses. To ensure equality and to guarantee a possibility for partly paid position for as many motivated students as possible, new student CEO and student project managers are recruited annually.

Most of theFIRMA's students are project team members, who are earning credits from their work. Students can complete their work placement, do optional studies, substitute appropriate courses or write their thesis in theFIRMA. The goal is that the student's skills are developing constantly and that each new project gives him/her a new set of skills and knowledge.

Since the operations of theFIRMA are student-oriented, the whole idea and working customs of theFIRMA are based on continuity and constant changes in human resourcing. Students are finishing their work placements or project studies, graduating or leaving for student exchange. Student project managers are holding one position for a year and then most likely heading towards graduation and working life. This kind of atmosphere has both pros and cons. First, there is a good chance for motivated students to climb up in theFIRMA's hierarchy. Second, it is easy to develop new good practices in the operation, because there are always new and fresh view available. On the other hand, it might be hard to maintain these practices, if there is no one to watch over them. Furthermore, changes in the project teams could have negative effect on customer satisfaction, if the changes are not systematically carried out. There is also a risk that the frequent changes in working environment will make the atmosphere seem disorganized and rushed, which might eventually lower the ability to manage all the projects.

These risks and development areas create a need for systematic project processes, which consists of learning and quality processes (Määttä, Roslöf & Säisä, 2017). For theFIRMA, quality policies and tools or philosophies have to be flexible and easily graspable, since students are not full-time employees. Also, there needs to be a chance for quick, small changes that can be implemented by anyone. Since its founding in 2015, theFIRMA's rapid growth has required the management team to focus also on quality issues. The best practice has proven to be continuous improvement, or "Kaizen".

KAIZEN

Kaizen is a Japanese term phrased from two words. It translates to mean change (kai) and good (zen). Roughly, it stands for continuous improvement, which is the main philosophy in theFIRMA. It is one approach to continuous, incremental improvement and based on the philosophical belief that everything can be improved. This means that even if there is a process that seems to be running fine, there is still something that could be done better. Following the Kaizen philosophy result in continuous efforts to improve, which will result in small changes over time. These incremental changes add up to substantial changes over the longer term, without having to go through any radical transition. This approach can be more employee-friendly way to institute the changes that must occur in any working place as the business grows and adapts to its changing environment. (MindTools, 2018.)

Japanese Masaaiki Imai introduced the term Kaizen in the 1986 in his book KAIZEN-The Key to Japan's Competitive Success. Originally the idea was developed in Japan after the Second World War, when the country's industry was rebuilt with the support of foreign manufacturing advisors, like William Edwards Deming. Since its breakthrough in western world on 1980's, Kaizen has suffered some criticism during the 21st century. Although many industrial companies have trusted its philosophy, it has not proven to be the right approach when facing the rapidly changing and globalizing, technological world. (The Economist, 2009.) This is quite understandable, as the philosophy relies on small changes that increment during the longer period. Kaizen is not probably at its best on large corporations as the only quality philosophy. On that scale, it needs some other tool by its side, that concentrates on more swift and major improvement. One example of this kind of application is Modular Kaizen, introduced by Duffy (2013), that allows both planned, fast changes and continuous improvement.

Kaizen has many underlying principles, which may vary a little depending on the point of view. However, the themes of these principles are the same. The human resources are a company's most important asset; processes must evolve by gradual improvement rather than by radical change and improvement must be based on a quantitative evaluation of the performance on different processes (The Economist, 2009). Finally, the work needs to be standardized in order to eliminate Muda, or waste, which means the activities that do not add value to work processes (Suárez-Barraza, Ramis-Pujol & Kerbache, 2011).

Behind these principles is the idea that all of the organization's personnel should take part in improvement process. People who do the work every day are the ones who have the knowledge, so they should also be the problem solvers. Leaders, on the other hand, should be more like coaches. Their job is to create an environment in which innovative thinking and learning, as well as the implementation of the employee ideas, can thrive. (Dyer, 2016.)

IMPLEMENTATIONS OF KAIZEN IN THEFIRMA

Mainly, theFIRMA's improvement methods follow the principles of Kaizen, although there has not been an official declaration that this philosophy is the one that is in use. However, the operation and internal improvement are tightly linked with each other as the operation is under constant development. For some employees (students of theFIRMA) it could be frustrating or confusing if the improving actions would be labelled with the word Kaizen, since it can be seen only as burdening extra work. On the other hand, naming the improvement methodology with actual term could make it more systematic and communal.

Internal development in student-run environment

TheFIRMAs student-oriented approach lowers the internal hierarchy and creates an atmosphere that encourages students to be self-driven and active, as emphasized in CDIO standard 8 (CDIO, 2004). The staff members of TUAS are not in any actual teaching role when working in theFIRMA, but rather in a mentoring or coaching role. This situation makes it easier for any student, not just for the management team members, to point out improvement ideas. As the Kaizen philosophy states, it also creates an environment for hatching and implementing ideas.

Working atmosphere is the key element when considering Kaizen for the improvement philosophy. It is vital that everyone in the working environment takes part in improvement, therefore it is essential to have an actual platform or situation for sharing these development ideas. The communication between the project teams, the management team and the staff of the TUAS is working properly already at the moment. The project teams have frequent internal meetings and in the weekly management team meetings the student project managers report about the projects to TUAS staff and student CEO. Both occasions are suitable moments for the students to bring up new ideas and improvement targets. There are also more unofficial online communication channels in use, where all the students of theFIRMA can discuss with each other.

In addition to those frequent meetings, there are bigger development events twice per year. These development days partly fulfill the characteristic of “Kaizen blitz”. Kaizen blitz is an organized event, kind of a formal problem-solving workshop designed to make specific and measurable improvements. These events can be very effective at solving specific problems and they can also demonstrate the power of continuous improvement, as the resulting improvements are measurable or can be clearly seen by different levels of the organization. (Dyer, 2016.)

Unlike the ideal Kaizen blitz, theFIRMA’s development events do not take several days, but one or a half working day. Otherwise the idea is the same and the goal is to get as many students as possible to participate, not just the student management team. Based on the issues and ideas presented on these events, the management team creates a task list and divides the actions to be taken. If possible, these improvement tasks are often handed back to the students that came up with them, so they have the opportunity to have an influence on the change. Task lists are reviewed in the management’s weekly meeting sometime after the actual event and the team checks how the ideas are proceeding in practice.

Growth creates a need for improvement

Both major and minor issues with resourcing and scheduling are tightly linked with each other. When considering a new customer project, the student CEO or staff members must first figure out if there are students available who could actually do the project. Even though there would be students with right skills or desire to learn them, they might be already taken by other projects or they are too busy with regular courses. On the other hand, there might be a free student who is not aware of a suitable project that is seeking an employee. Because most of the students in the projects are awarded with credits, the project needs to be motivating and also teach the project team new skills. There is no point in doing five similar video editing projects in a row.

After the human resourcing comes the question about the new customer project’s scheduling. In most of the cases the project deadline is set so that there surely are capable students with enough time for the learning and implementing the project. Sometimes though, for the reasons described in *TheFIRMA’s operation and management*, the project team needs new students. This recruitment process, even if it is short, might have an effect on keeping up with the deadline. Changes on the team and possibility for not meeting the deadline can lower the customer satisfaction. The process of figuring out who is going to do the project, managing it and the time frame in which the project can be accomplished takes a lot of unnecessary time.

Premises and online tools support the learning

Since aforementioned problems are the most apparent, there have already been several improvements implemented regarding them. For example, student project managers have listed their projects and deadlines to an online service and divided their available time to between the projects. The online service is convenient in this case, because staff members or the student CEO can check the management's resource situation even during a customer meeting. Online version of the timetable is not always the best option, though. During the autumn 2017, best practice for marking daily office hours for student project managers proved to be X-marks on a whiteboard. Every student in the office can see when the student CEO or student project managers should be available.

Ongoing projects, their statuses, deadlines and resource needs are controlled both with physical Kanban-board on whiteboard and on online platform. Idea of the physical board is that any student or visitor is able to see the different code-named projects' statuses with one glance. Figure 1. shows that visualizing things often makes them more real, so when some project status is marked with an alarming red, it is the last wake-up call for the student project manager responsible for the project. Luckily, this rarely happens. Online service is more useful for the TUAS staff members, who are not present at theFIRMA's office all the time. They can see which projects need more students and which are concluding soon.

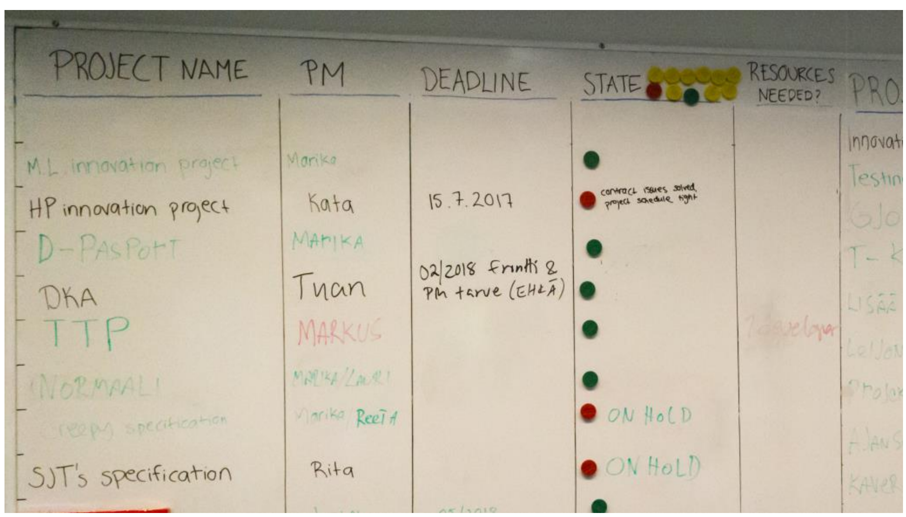

Figure 1. Visual project management board in theFIRMA. Project names are coded, since various visitors visit the office.

Although theFIRMA's office locates inside the school building, it does not have a common classroom's layout. Figure 2 shows that office layout is built with the ideal team work opportunities in mind, and it supports the learning process as stated in CDIO Standard 6 (CDIO, 2004). There are places for internal and customer meetings and desktops are organized so that people working within the same project or field, such as programming, are sitting near to each other. The management team also have places near to each other. There are no walls between workspaces, the only exception is the customer meeting area which has medium height sound proofs around it. This kind of layout makes the communication fairly easy, and there are still opportunities for quiet workspace. With the goal of theFIRMA being to transfer knowledge from a student to another, it is only practical that they are seated close to each other. Students are responsible for the layout, so they can adjust it as they see best fit.

Figure 2. Students working in theFIRMA's office. TheFIRMA's brand color is blue, which inspired the students to brighten up the office by painting one wall blue.

Engaging environment and atmosphere

One part of resourcing is trying to engage the students in theFIRMA for a longer period. They can start their career as a trainee or through the optional project studies, but the goal is that they keep doing projects and gaining credits also after that. According to a text-book career path, the student comes in to theFIRMA through optional project studies, then stays for the work placement and then gets hired for the student project manager or student CEO position. This path does not always actualize, though. During his/her career, the student’s skills widen and develop from junior to senior level. They are completing their studies while working in theFIRMA and graduating with actual experience on ICT customer projects. In order to engage students, theFIRMA has to have new and interesting projects, a supportive atmosphere and a chance to make an impact. Balancing between studies and growing responsibility in theFIRMA can lead to waste of overburdening, muri. It is caused by lack of training, unclear instructions and unreliable processes (Lean Manufacturing Tools, 2018).

In theFIRMA, there has been several actions towards an engaging and non-burdening environment. For example, the orientation process has been developed with small steps. Previously, no one was responsible for introducing the general customs for the new students in theFIRMA. This led to a situation where the orientation of the new students was inconsistent – or lacking. First step was to create an introduction checklist that the student CEO uses to ensure that all of the necessary things have been told to new employee. Second step was systematic, three-day long introduction period for new trainees. During that time, new trainees familiarized themselves to the most used tools and software of theFIRMA, as well as to the basic working customs. The latest improvement has been that all of the information from the previous introduction checklist is now stored in the online environment, that all students of theFIRMA have access to. The material was both created and peer-reviewed by students themselves. All these steps support each other and together they create a successful start for the new student, who does not need to wonder what to do or whom to speak to.

The goal of the proper introduction is to ease student's adaptation to theFIRMA and its working customs. Team spirit building is done both in official occasions, like the project team meetings, and more unofficial occasions, like office gaming or other common events. All these events are organized by students themselves, usually by the student CEO and student project managers. Unofficial team building activities have a positive effect on the working atmosphere, which is one important element in engaging students. Little things, such as having lunch together or the weekly Friday board game night, could make a significant difference.

Productive platform for Kaizen

Besides the atmosphere and adjustable processes, continuous development fits well with theFIRMA due to the skillful students available. Besides the customer projects, students are constantly learning new skills on school courses. One student might have some idea for visualizing the data while in the project management class, and another student in theFIRMA might be able to program a tool for the visualization with ease. It is not a common situation in an organization, that the developer for the idea and the one implementing it sit next to each other in the office. With the backup help from the teachers, it is possible to develop small software for internal use that can have a great affect for example to the student CEO's work load.

Cycle of the students from a role to another within theFIRMA is a productive platform for Kaizen. For example, a new student CEO can pick up where the previous left off and continue improving processes further. Whether the students are just starting in theFIRMA or climbing up in the internal hierarchy, they spot the improvement needs there where previous employee saw only a properly functioning process. Since the majority of the responsibility is given to the students, they have also the opportunity to fulfil these improvement ideas. This enables the operation to be under constant development and progress.

FUTURE POSSIBILITIES OF KAIZEN IN THEFIRMA

Since theFIRMA has succeeded in creating an atmosphere where its employees can actively take part in continuous development, the next step is to standardize improved processes. In theFIRMA, standardization stands for a formal and stable process, which can be used in various parts of its operation. Ironically, for the same reasons that continuous development is possible in theFIRMA, the standardization is quite hard. Usually developing processes takes some time, since the customer projects have to be prioritized over internal development. This means that the time between idea and finished implementation can be long, and the developer for the idea has moved on to new tasks or does not have time to oversee the standardization. Active movement from tasks to another is vital for internal development, but hard for standardization. The less management effort or time is needed for standardization, the more likely standardization succeeds.

Muda refers to non-value adding activity or process, which is a physical waste of time, resources and eventually money. Muda can be divided further into seven wastes, but they are not covered in this paper. Mura, on the other hand, is the actual root cause behind those wastes. It refers to waste of inconsistency and unevenness in processes. For example, measuring operation on monthly basis, can lead to rushing in the final week and then starting the next period slowly with no focus on meeting targets (Lean Manufacturing Tools, 2018).

Kaizen's goal is to minimize the waste in processes. Issues with standardization in theFIRMA originates from the waste in processes and on daily activities. Part of the already limited working time is consumed by muda, thus getting rid of the waste in daily activities is one of theFIRMA's future improvement areas. In time, it will free time for the customer projects and help the atmosphere feel less rushed. Other important part of this is getting rid of the mura in project management. There is sometimes a slow start to the projects, that should be avoided at all costs. This will require more systematic project management plan and good requirement and timetable specifications right from the start of the project. Proper communication and systematic training into these practices will help avoiding muri and decrease the risk of overburdening.

To make processes worth developing and standardizing, the improvement should be somehow measurable. Currently, the customer feedback is the main measuring way of the quality of the operation. Positive feedback and processes that led to it should be highlighted in weekly management and project team meetings. Collecting of the feedback should be more systematic and they could be stored in some general database, where both students and staff members would have an access. Other measurement actions could be clear and transparent status reporting for all theFIRMA's students, showing the improved situation a year ago and the current situation.

CONCLUSION AND DISCUSSION

In this paper, Kaizen was examined as the continuous development philosophy for the project-based learning environment theFIRMA. The environment itself creates a fine platform and atmosphere for Kaizen, since it is student-driven by the support of coach-like teachers. In theFIRMA, Kaizen has already provided several improvements, and for example annual Kaizen blitz -like development events are organized multiple times per year. Despite the actions towards more efficient working environment with less waste, there are still processes left to improve. Since students are working in theFIRMA mainly part-time, their time is valuable and should not be filled with waste.

CDIO Vision states that the gap between engineering education and real-world demands on engineers should be closed (CDIO, 2004). TheFIRMA is following this vision by encouraging students to widen their skills through customer projects. Kaizen in theFIRMA ties the education and working life even closer together, as students can actually see the results of their own internal development and learn to take actions towards even more efficient working environment.

In conclusion, student-driven environment both enhances the implementation of Kaizen philosophy, but it also brings up issues that might make the improvement, especially the standardization, more difficult. This has been identified, and development for that area is in progress. In addition, in the future the measurement between the change and result, such as customer feedback, should be more transparent, for example if some changes are made, do they have an effect on customer or employee satisfaction. In the spirit of Kaizen, there will always be something to improve.

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BIOGRAPHICAL INFORMATION

Katariina Tiura is an engineering student in the ICT unit of Turku University of Applied Sciences, majoring in Information and Communications Technology. Besides her studies, she has been an active student in theFIRMA, working as a student CEO and student project manager. Currently she works as a student project manager in externally funded project Inside the Box.

Marika Säisä is a project manager in the ICT unit of Turku University of Applied Sciences. She holds a Master of Science in Technology degree from University of Turku (Finland). She is responsible project manager in theFIRMA, mainly concentrating on customer relations and mentoring students with customer projects. She has participated in several national externally funded projects. Currently she works as a project manager in Inside the Box and Hot Potato.

Corresponding author

Katariina Tiura
Turku University of Applied Sciences
Joukahaisenkatu 3
20520 Turku, FINLAND
+358408356331
katariina.tiura@edu.turkuamk.fi

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VIDEO DEVELOPMENT METHODS FOR CDIO-BASED PROJECT COURSES

Panagiota Papadopoulou, Kanishk Bhadani, Christian Stöhr, Erik Hulthén, Magnus Evertsson, Johan Malmqvist

Chalmers University of Technology

ABSTRACT

Video utilization can be a powerful tool for teachers to stimulate students' interest and support flexible and adaptive learning. Successful video-based learning implementation cannot be assured without careful consideration regarding desired quality, learning outcomes and video development methods. The investigation and sharing of experiences considering video development is indispensable and will contribute to spreading a culture of easily made, peer-reviewed videos, which will enhance teaching and learning. For CDIO-based courses, it is required that the video development methods are agile and cost-effective in production as to support continuous update of videos relevant for the course and other course activities. In this paper, we identify and describe video development methods from different CDIO-based project courses. The methods are classified based on the content type, the production style, the required resources and the video characteristics. All presented video development methods follow our general framework of video development process which has been previously published and consists of four interwoven steps - topic selection, learning objectives mapping, content generation and video recording. Based on semi-structured interviews with the course teachers, we present their experiences with those different development methods to create content specific videos pertaining to various *Conceive-Design-Implement-Operate* topics. As outcome, we suggest our preferable video development method depending on video content category. We conclude that the choice of video development method must consider the audience's characteristics and needs while video content should be aligned with the course content, other learning activities and the literature. The video development methods suggested and described in this paper will assist educators to choose an appropriate video development method for their own courses and maximize the videos' contribution to student learning.

KEYWORDS

Video-based learning (VBL), Project-Based Learning (PBL), Design-build-test (DBT) project
Standards: 2, 5, 8, 10

INTRODUCTION

Due to the increased affordability of technology and the development of learning sciences in the past decade, a growing number of teachers in higher education use videos in their teaching to facilitate their students' learning in blended or virtual learning environments. Application of video-based learning (VBL) is an accumulated effort involving video-planning, content-development, video-usage, and monitoring aiming for continuous improvements. Merely video usage does not lead to better learning outcomes, but careful considerations regarding the quality, learning outcomes and video development methods are required. In CDIO-based project courses, VBL can assist to multiple course-activities such as to conduct workshops or assist in project assignments. Therefore, it is required that video development methods used are agile and cost-effective in production to support continuous update and creation of new videos relevant to courses.

Preparation and recording of well-adapted videos can be time and cost intensive (Viksilä, 2013) and requires a sound pedagogic foundation. Therefore, studies have been conducted to provide guidelines or suggestions for video creation aiming to help teachers to produce their own videos (Plaisant & Shneiderman, 2005; van der Mei & van der Meij, 2013). Those guidelines are also applicable to videos developed for CDIO courses. However, to be more effective, the choice of the method should be based on the video content category, whether it refers to a Conceive, Design, Implement or Operate topic. Additionally, due to the inclusion of design-implement experiences in many CDIO courses, emphasis should be given on how to develop videos for this purpose. Currently, there are few references regarding the use of video-based learning in CDIO courses (Bhadani et al., 2017; Viksilä, 2013) and just one study considering video production in problem solving videos (Sellens, 2014). Therefore, there is a need to investigate the correlation between video content and production style in CDIO-based project courses. The purpose of this paper is to expand the research and systemize video development methods for CDIO-based project courses by answering the following research questions.

- What are the main components of a video development method?
- Which production styles are more suitable for different video content?
- What problems do teachers encounter while creating or using videos and how could those problems be mitigated?

The paper contains a brief description of the previous research followed by a description of our research methodology and data collection, which includes self-reflection and interviews with teachers. Our results consist of an overview regarding classification of video content, production styles, resources and video characteristics such as duration, narration, quality, presentation style. Further, a brief analysis of teachers' experience regarding video development is also presented followed by discussion. We conclude with suggestions to teachers on how to choose video development methods based on content characteristics aiming to produce their own adaptable and cost-effective videos.

LITERATURE REVIEW

Research on video-based learning has increased over the last decade (Giannakos, 2013). A number of studies have thereby examined the effect of video usage on student performance (Means et al., 2010; Nikopoulou-Smyrni & Nikopoulos, 2010) and student satisfaction (Bhadani et al., 2017; Kay, 2012) in varying academic environments. The results tend to vary somewhat but studies indicate that - compared to traditional teaching - video-based learning has either positive or no effect on students' performance and that students tend to have a positive attitude towards videos. Similar findings were also presented for video-based learning in CDIO courses (Cheah, Lee, & Sale, 2016; Hugo, 2014). However, Basu Roy and McMahon (2012) supported that video usage could also have negative effects and lead to decreased deep thinking compared to text-based teaching if videos are not prepared according to their purpose. Therefore, video design should be considered carefully. Despite the growing trend of using video-based learning, there are only a few guidelines or methods on how to develop short videos, which is the suitable video-type for CDIO-based project courses (Bhadani et al., 2017; Sellens, 2014).

Documented video development methods focus mainly on content development and video characteristics, such as duration, narration, audio-image correlation and quality. They may refer to a specific type of video content, for example tutorials (Blummer & Kritskaya, 2009), to a specific production style, for example screencasts (Oud, 2009), or to general guidelines (Guo, Kim, & Rubin, 2014). Their basis can be either practitioners sharing their experiences on how to develop video content in an effective and engaging way (Martin & Martin, 2015) or guidelines originating from an established theory, such as the cognitive theory of multimedia learning (Mayer, 2007) or the observational learning theory (van der Meij, 2017), aiming to reduce cognitive load imposed to students through videos (Koumi, 2013) or to address students' multiple learning styles (Mestre, 2012).

Video development methods can refer to videos either for purely web-based courses such as in distance education or Massive Open Online Courses (Hew & Cheung, 2014) or for blended courses that also include face-to-face interactions. This can, for example, be traditional courses where videos have an assisting role (Kay & Kletskin, 2012) or courses that apply a flipped classroom model (Karabulut-Ilgu, Jaramillo Cherrez, & Jahren, 2017; Svensson, Hammarstrand, & Stöhr, 2015). In both cases, videos developed use similar production styles but differ in the targeted audience and production budget. Videos in CDIO-based project courses are mainly used in a blended learning environment involving a relatively small number of students (up to 150) and the available resources for their development are usually low compared to those of Massive Open Online Courses. Therefore, although video development guidelines developed for Massive Open Online Courses or distance education are also applicable to CDIO courses, adaptation is needed to create videos tailored to project-based course format, where additional videos may be needed within a short notice for project assistance, and speed of delivery has priority over quality. As a result, emphasis should be given on how to develop short videos for varying contents quickly, using a reasonable amount of resources and maintaining a good enough quality to fulfil the educational purpose.

METHOD

The suggested video development methods were investigated in three steps. Firstly, an analysis of the developed videos was conducted to identify the components of the video development methods. Around 30 videos were analyzed resulting in the categorization of the video components. The videos were developed for three courses: Machine Elements (PPU210), Product Planning - Needs and Opportunities (PPU085) and Engineering Design and Optimization (PPU190) in the Mechanical Engineering program at Chalmers University of Technology. Secondly, semi-structured interview was chosen as a method to initiate a fruitful conversation with the faculty members and gather different perspectives on video development approaches. The interview's structure was decided after the initial identification of the video development components and aimed to cover all the sections of a video development method: Content, Production Style, Resources and Video Characteristics. Lastly, suggestions for video development methods were made based on our personal experience of video development during the past two years and on the four semi-structured interviews with faculty members who created the videos themselves.

RESULTS

The result section is divided into two sections: description of components in video development methods, comparison of the components based on teachers' experience. Further, an analysis of the interviews along with recommendations are presented.

Description of Components in Video Development Methods

The components of video development are broadly classified into four categories, namely, Content, Production Style, Resources and Video Characteristics which are described below.

Content

Content of a video refers broadly to the various aspects of the course topic to be presented in the video. Figure 1 presents the classification of the Content consisting of Category, Course Activity, Type, Purpose and Difficulty. Category refers to the classification of video in Conceive (C), Design (D), Implement (I) or Operate (O) according to CDIO syllabus and the learning outcomes. The videos are designed for various course activities which can vary from theoretical lectures to more practical assignments, lab exercises and workshops. Content type can be Methods & Examples (ME), where theory and applications are described, Software Demonstration (SD), where the software features with a problem are presented, Problem Solving (PS), where the solution to a specific problem is sequentially explained and Assignment Procedure (AP), where information regarding a specific assignment or project is included.

Videos can have multiple purposes, especially in a project-based course. More specifically, they can be used to prepare students for course activities allowing more productive use of the allocated time or they can repeat something from a course activity for students who could not attend or for those who need a reminder. They can also be used as a direct action from the teacher by answering students' questions when many of them encounter difficulties in a specific part of the theory or a procedure. In this case, videos can save time from teachers and supervisors in assisting students to understand a trivial part and to continue their project assignments. Additionally, videos may contain extra material aiming to level the class, especially at Master's Level where students may have different studying background. The last aspect of content classification is the difficulty which may vary from an entry level to an advanced level.

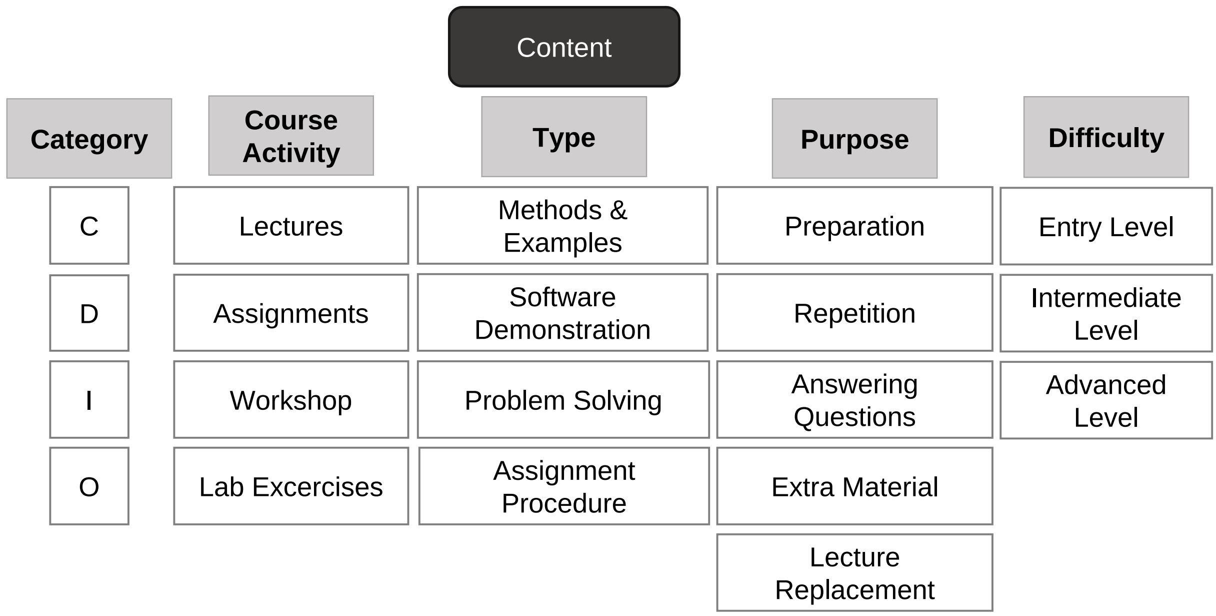

Figure 1. Content classification in a video development method

Production Style

Production style refers to the different electronic means that can be used to record the content of the videos (see Figure 2). It can be via PowerPoint slides recording, screencasting, camera recording, surface tablet recording or a hybrid method consisting of two or more production styles in the same video. Screencasting refers to recording of content presented on a computer screen and it may also include simultaneous recording of audio. Camera recording can be either recording of a person's hand while writing on a paper or recording of a person while performing a task on a board. Surface tablet recording describes the recording of the screen of a tablet device, where a person writes by hand or using stylus. The production style is closely associated with the available resources for developing video and user's choice.

Resources

Resources refer to software and hardware used in each production style and location in which the video can be recorded (see Figure 2). In this study, the software used were PowerPoint Mix for slide recording with minimal editing, and Camtasia Recorder or Screencast-O-Matic for screencasting with more comprehensive editing. Both Camtasia Recorder and Screencast-O-Matic have a free basic version which is sufficient for short video recording in case there is not a purchased license. The advantage of PowerPoint Mix is that users can record the PowerPoint slides one by one which adds flexibility to the recording and modification of the video. However, it does not include advanced editing options which can be found in Camtasia Recorder. Hardware used included personal computers or laptops with built in or additional cameras and microphones for voice recording, a wolf camera for recording a person's hands, which can also be used to record a pen and paper style video, and surface tablets with pens which were used to add handwritten notes to slides or screen recordings. All videos analyzed in this study were recorded either in the person's office or at their home in case it was not possible to use their office or if they did the recordings at their spare time.

Video characteristics

Video characteristics refer to video-duration, narration, quality, and presentation style (see Figure 2). In this study video duration ranged from less than 1 until up to 18 minutes. When videos were larger than 20 minutes they were segmented into smaller duration creating a series of videos.

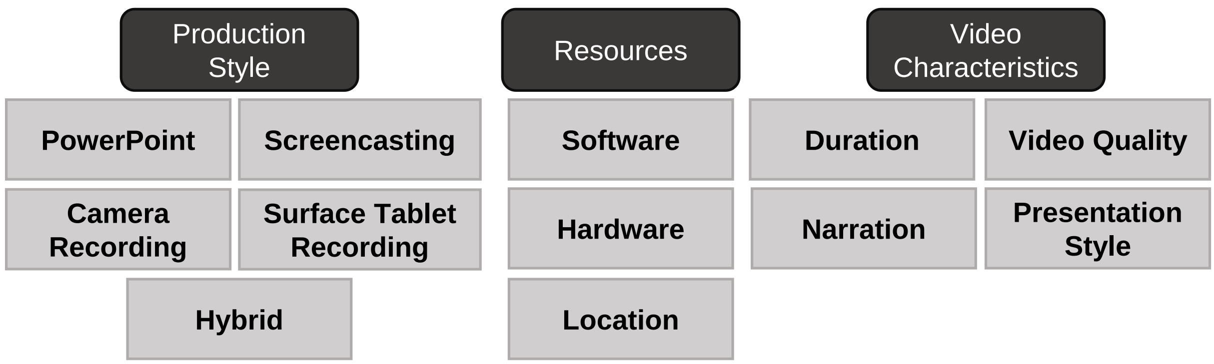

Figure 2. Production Style, Resources and Video Characteristics Classification in Video Development Methods

Narration refers to the talking style, whether it is formal or conversational, the use of a script, and the relation between the person recording the video and students. Video quality refers to both sound and audio quality. In this study, the targeted video quality was reduced to facilitate quicker video creation. Presentation styles refer to the incorporation or not of annotating tools, zooming and instructor's face. In general, the videos had a casual conversational style and there was a personal contact with the students as the person recording was either the professor having the class lectures or teaching assistants acting as supervisors.

An analysis of the evaluated videos with respect to the components of the video development methods is shown in Figure 3. For course topics related to *Conceive* category, PowerPoint was mainly found suitable for the user whereas for videos related to *Design* category, the user preferred using a hybrid style of video, usually screencasting of software and PowerPoint or screencasting of PowerPoint and use of a surface tablet. This trend can be related to the need of switching between topic presentation and software demonstration to create a comprehensive video. The *Implementation* category mainly contained videos aiming to provide additional support to students in their assignments and screencasting was mostly used for this category.

Comparison of the components of video development based on teachers experience

Interviews were used to investigate how faculty members formulated their video content, what production styles they used, what resources they needed and what was their overall impression about the videos they produced. The summary of the interviews is presented in Table 1. The interviewees were categorized based on their teaching and video development experience. All of them were considered beginners in terms of experience in video development. However, their teaching experience was substantially varying. The analysis of the students' reactions to the videos is not part of this paper, but is presented by Bhadani et al. (2017).

Inner Circle- Content Category

C	Conceive
D	Design
I	Implement

Middle Circle- Purpose

Prep	Preparation
AQ	Answering Questions
LR	Lecture Replacement
Extra	Extra Material
Rep	Repetition

Outer Circle- Production Style

PP	PowerPoint
SC	Screencasting
Hb	Hybrid

Figure 3. Classification of analysed videos to components of video development

Table 1. Teachers' view on video development methods

	A	B	C	D
Teaching experience	Beginner (2 years)	Intermediate (8 years)	Experienced (25 years)	Experienced (25 years)
Video creation experience	Beginner (approx. 20 videos)	Beginner (approx. 15 videos)	Beginner (approx. 10 videos)	Beginner (approx. 10 videos)
Content Type	Methods & Examples, Software Demonstration, Problem Solving	Software Demonstration, Assignment	Methods & Examples	Problem Solving
Content Purpose	Preparation, Extra Material, Lecture Replacement	Extra Material, Repetition, Answer Questions	Extra Material	Extra Material
Production Style	PowerPoint, Screencasting, Hybrid	PowerPoint, Screencasting, Camera Recording, Hybrid	PowerPoint, Screencasting	PowerPoint, Screencasting
Resources	PowerPoint Mix, Camtasia Recorder, Surface Tab Pro, Extra microphone	PowerPoint, Screen-O-Matic, Wolf camera, Surface Tab Pro	PowerPoint Mix, Camtasia Recorder; Surface Tab Pro, Extra Microphone	PowerPoint, Screen-O-Matic
Recording Location & Time	Office, Up to 1 day/video	Home, Office, Up to 1 day/video	Home, Office, Up to 0.5 day/video	Office, Up to 1 hour/video
Video Characteristics	Up to 15 minutes, casual narration, use of script, use of annotation-red pointer, zoom feature, use of talking head for M&E topics	Up to 30 minutes, casual narration, use of script, use of annotation, use of talking head for M&E topics	Up to 10 minutes, casual narration, no script, use of talking head	Up to 10 minutes, casual narration, no script
Suggestions	Perform editing on same day of recording, get reviews for your content before recording, create interactive content and suggest literature during video	Keep same layout of the information between lectures and videos, make clear video purpose to students, extra microphone-set it correctly from the beginning	Use segmentation for long topics, invest time in preparation, use subtitles	Include follow up quiz, ensure students work themselves and not passively watch videos, not too compacted video content, fewer problems with more time for explanation

Motivation for video development varied between the interviewees. Two of them considered that videos could be a good tool to assist many students in solving their assignments, while the other two wanted to follow the trend of online teaching and observe students' response. None of them received formal training in video development and their approach was to just start trying recording and improve video quality through iterations. The equipment they used was provided by the university. Regarding the content development, most of the times they used existing lecture slides from course and sometimes, they created new content as well, especially when it referred to assignments. When they used existing content, they usually modified it to be more suitable for video recording by adding annotations or dividing the topic into smaller segments to make shorter videos. Three out of four interviewees preferred to spend more time on preparation of the content and the narrative to avoid time-consuming editing.

Table 2. Pitfalls and suggestions to avoid them

What can go wrong?	How to avoid pitfalls?
Video preparation and recording lasts longer than expected and videos are not ready on time.	Emphasize over fast delivery and content quality against video recording quality.
Videos do not convey the desired message.	Consider learning objectives in the design of the videos.
Video creates more problems to the students than it solves.	Maintain same layout between lectures and videos, avoid distractions and misunderstandings.
Students are not interested in the videos.	Choose the appropriate production style based on the content classification. Develop short (2-15 minutes) videos with good enough quality.
Students watch passively and do not practise, their performance deteriorates.	Include interactive elements to involve students.

Regarding flexibility of re-using the videos, one of the teachers indicated that the videos may seem aged after a while, because lecture notes were changed but not the videos since it is time consuming to renew them. One of the interviewee pointed that the use of camera recording is an important tool especially for the problem-solving topics and it can be used to create a presentation by hand at the time of recording and replicate students' way of working while providing intuition to the solution. This can serve as a reminder to students that not everything can be done on a computer and that they should perform hand calculations as well. Another interviewee suggested that video content for problem solving should not provide the solutions to the students in a straightforward way but it should challenge them to think. Additionally, it should be complimented with hands-on exercises to engage the students actively. Table 2 includes a summary of the main issues during video production and how to avoid them based on the authors' self-reflection and the interviews with the faculty members, where they identified problems they encountered during video production and use.

DISCUSSION

The paper identifies the main components of a video development method and which production styles are more suitable for different video contents. This is the first approach to identify suitable methods for video development in CDIO-based project courses. The interviews with the teachers tried to identify the problems they faced and their suggestions for more efficient and effective video development. There were mainly two categories of problems, the first concerned the teachers themselves and the fact that they may lacked time to produce videos or they delayed their delivery. The second category referred to the students and how they interacted with the videos based on the teachers' observations. Typical problems in the second category were that the video could create more confusion to the students than understanding, students may not be interested or they watched passively without really understanding the concepts presented.

As measures to the above problems it is recommended that the videos have clear objectives and are aligned with course's learning outcomes, while students' engagement and their evaluation during and after watching the video should also be considered, which is in-line with the recommendations by Blummer and Kritskaya (2009). It is also advised not to use outdated videos in tutorials if the content has changed considerably and segment the videos to lower the duration which is also supported by Martin and Martin (2015). It is also suggested the use of conversational and friendly narration style to imitate classroom environment which was also recommended by Mayer (2007) and Koumi (2013). Additionally, the creation of short videos and the minimum post-editing to ensure good enough quality are also proposed to maintain students' attention and save time during video production. Those are partially in-line with suggestions by Guo et al. (2014) who recommended an informal setting with casual narration and post-production editing. The difference between the two approaches regarding post editing could be explain by the different targeted audience and the context of the videos in terms of size and purpose between Massive Online Open Courses and CDIO courses.

CONCLUSION

This paper identified four central components in video development methods, namely, Content, Production Style, Resources and Video Characteristics and it describes the different alternatives in each case. The analysis can assist teachers to choose the most appropriate production style for their video based on the content category and the purpose of the video and get an overview of good and bad practices for the different components. For videos in the *conceive* category, PowerPoint is suggested as a production style and for *design* videos a hybrid method may be more suitable to produce comprehensive videos. *Implement* videos usually refer to software demonstrations and therefore screencasting or a hybrid approach is proposed for production style. While differing in terms of production style, the video development methods are adaptable and cost-effective in terms of the required technologies. This study is limited by the content of the courses that videos were created for and the relatively small number of videos examined. However, this approach of video development could be potentially implemented in video development for project-based courses with similar content. The main implication of the study is the preservation of the knowledge acquired during those two years regarding video development and the creation of a video component classification method which can act as a basis for further investigations in more courses.

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BIOGRAPHICAL INFORMATION

Panagiota Papadopoulou is a Project Assistant at the Department of Industrial and Materials Science at Chalmers University of Technology.

Kanishk Bhadani is a Ph. D. student at the Department of Industrial and Materials Science at Chalmers University of Technology. His current research focuses on optimization in minerals processing.

Christian Stöhr is a Senior Lecturer at the Division of Engineering Education Research at Chalmers University of Technology. He has performed extensive research and capacity building within e-learning and blended learning in engineering education and has also contributed to STS research in environmental governance.

Erik Hulthén is an Associate Professor in Product Development and Director of Masters Programme in Product Development at the Department of Industrial and Materials Science at Chalmers University of Technology

Magnus Evertsson is a Professor in Machine Elements and head of the Product Development Division at the Department of Industrial and Materials Science at Chalmers University of Technology. He leads also the Rock Processing Systems research group.

Johan Malmquist is a Professor in Product Development and Dean of Education at Chalmers University of Technology, Göteborg, Sweden. His current research focuses on information management in the product development process (PLM) and on curriculum development methodology.

Corresponding author

Kanishk Bhadani
Department of Industrial and Materials Science
Chalmers University of Technology
SE- 41 296. Göteborg, Sweden
+46 3177 250 03

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FOSTERING ENGINEERING THINKING THROUGH INTELLIGENT ELECTRONIC PRODUCTION PROGRAM AT NIT SENDAI COLLEGE

Kazutaka Baba, Nahomi M. Fujiki, Tadayuki Hayashi, Yasuhiro Kashiwaba, Koji Kawasaki, Senshi Nasu, Mio Sakuma, Shigeyuki Seki, Jun Sonoda, Takatoshi Suenaga, Tetsuya Ooizumi and Takahiro Yonamine

Dept. of Intelligent and Electronic System, National Institute of Technology, Sendai College, Sendai, Japan
E-mail fujiki@sendai-nct.ac.jp

ABSTRACT

NIT Sendai College offers a practical training course called Intelligent Electronic Production program that has been conducted in its own curriculum since 2013. Senior students are supposed to develop a self-propelled robot which runs a certain course tracing a line and performs different assigned tasks. Basic components are provided but students have to design the rest of the necessary parts to realize various functions within the fixed budget. This program is the compilation of what the students have learned so far. Each robot is shown at the final contest on the college festival day. They compete for run time, accuracy of movement, stability, and appeal of their own robots in front of public spectators. Through this project- based learning program, students are expected to foster skills of managing the project work with other members in a group, applying their technical knowledge, and demonstrate application of engineering thinking to practice.

KEYWORDS

Project-based learning program, engineering thinking, self-propelled robot, group work, Standards: 4, 7, 10, 11

INTRODUCTION

Colleges at National Institute of Technology (NIT) in Japan are well-known as institutes that produce leading engineers with high skills and have long-term experience with PBL (Project/Problem Based Learning) education systems. These NIT colleges offer 5-year intensive education programs to foster engineers with practical skills. Students enter the college at the age of 15 and continue developing his/her technical skills for 5 years. The importance of practical trainings is emphasized in the curriculum of every NIT College. NIT Sendai College has also been offering spiral-shaped training programs with lectures followed by PBL type practices and has recently adopted more Active Learning methods in classes (Fujiki N.M. et al 2016). Engineers in the next generation are required to have more and more flexible thinking and heuristic approaches to solve various issues. PBL is one key program at the NIT colleges to train students in various abilities so that they can adapt positively to society with complex economic structures, global competency, and rapid development of technology in the 21st century.

In the Department of Intelligent Electronic System at NIT Sendai College, the practical training program, called the Intelligent Electronic Production program, has operated with its curriculum since 2013. This program is offered to our senior students and the core objective of students is to develop a self-propelled robot which traces a line and completes different specified tasks (CDIO standard 5). Through the work on this practical project students are expected to conceive how to solve the given assignment, design various functions based on their ideas and implement their ideas to develop processes of a robot. At the same time they also learn cost and time management, how to work efficiently in a group, and how to apply knowledge that they have acquired previously in various lectures and experiments. Through this integrated learning experience, students could develop important skills required for future engineers such as engineering design implementation, ability to manage budgets, working in a team, and integrating all type of knowledge that they have(CDIO standard 4 and 7). The teaching staff acts an advisor who keeps an eye on students' progress on the project and properly identifies what may be blocking their progress. The enhancement of faculty teaching competence is also required.

This program should be a compilation of what the studies have learned thus far. Each robot is shown at the final contest on a college festival day. The students compete for run time, accuracy of movement, stability, and appeal of their robots in front of public spectators

INTTELLIGIENT ELECTRONIC PRODUCTION PROGRAM

The main objective of Intelligent Electronic Production program is to provide students an opportunity to learn how to integrate practical knowledges about electric and electronic circuits, mechanics and software and to experience to creating their own machine through this PBL type project. We expect that students will struggle and work hard to find solutions for problems they will face during the program and acquire not only engineering thinking skills but also generic skills from their failures and trials. All these skills are surely required in their future when working as engineers.

An on-board microcomputer controls various sensors such as an infra-red sensor or a position sensor and motors to enable a self-propelled robot to trace a line successfully and to accomplish different tasks on its way. This program is offered to students of the 4th grade in the Department of Intelligent Electronic Systems. Three or four students form one group and work on the project 6 hours per week for one and a quarter semesters that takes roughly over 20 weeks.

The list of previous themes since 2013 is shown in Table 1. The theme "Open up the positive gate" in 2017 is that a robot traces a black line and/or runs along a wall controlled by the data from a position sensor, counts markers on the field, and decides which gate to open. The maximum budget for robot production is limited, but students are free to select mechanisms to achieve assigned robotic tasks and design of the robot's frame as well. How to pursue the development of a robot or assign the specific role of each student in a group is left to students. In this way, students learn not only technical knowledge and characteristics of electric devices, but also how to manage group work and/or realize their own ideas within a limited budget.

Table 1. Previous themes since 2013

FY	Themes	Key Elements
2013	Find gold mines	Metal detector and photo reflector
2014	Shoot balloons like William Tell	Position sensor and photo reflector
2015	Find and Deliver Chi-Ele. delivery service	Metal detector and photo reflector
2016	Chi-Ele Treasure hunter	Color sensor and photo reflector
2017	Open up the positive gate	Position sensor and photo reflector

Evaluation of results for each student is determined comprehensively based on points according to the required performance of the robot from each group at trails, and contribution to group work, and the presentation observed by the teaching staff.
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MODULE DESIGN

The module design is summarized in Table 2. The first part of instruction is designed to introduce students to the concepts of this program and to explain the theme picked for that year. After a few weeks of preliminary lectures and experiments students start working on their own robot production. A progress report is requested to submit every week and core functions of the robot are checked periodically. The whole operation is delivered in the project- based learning (PBL) style and the teaching staff acts as facilitators to encourage, risk taking, to correct errors and to support smooth operation of their work. On the other hand, students consider what kind of technical requirements they need to realize the tasks and design the proper mechanisms of a robot with certain electronic devices, motors, and other parts. SOLIDWORKS is an application for 3D CAD provide to the students to design the main frame of the robot. The basic kit includes a TAMIYA Inc. Remote Control Robot Construction Set (Fig.1) and a programmable microcomputer LPCXpresso LPC1769 board as the development platform (Fig.2) is provided.

A sample course for the production program in 2017 is shown in Fig.3. The black line disappears in the middle of the course, and walls are placed instead of the line. There are gates on the course and robots must decide which side of the gate to open based on the number of horizontal short lines drawn before the gate.

Table 2. Module Design

Week1	Guidance and announcement of a theme for the year Explain the tasks and the rules
Week2 -Week3	Lecture and workshop about infrared sensors, power circuit and DC motor Fundamental exercises on basic elements
Week4	Lecture on electronic circuits and preparatory experiments and design of a robot
Week5	Lecture about position sensor and RC servo motor, the micro-computer Fundamental exercises on basic elements Submission of project protocol
Week6 -Week17	Production of a self-propelled robot in a group Submission of a weekly report
Week8	Check line trace capability of each robot
Week13	Presentation to assess the progress of each team
Week16	Check basic movements of each robot
	Root competition at the college festival
Week18 -Week20	Final adjustment Submission of final reports

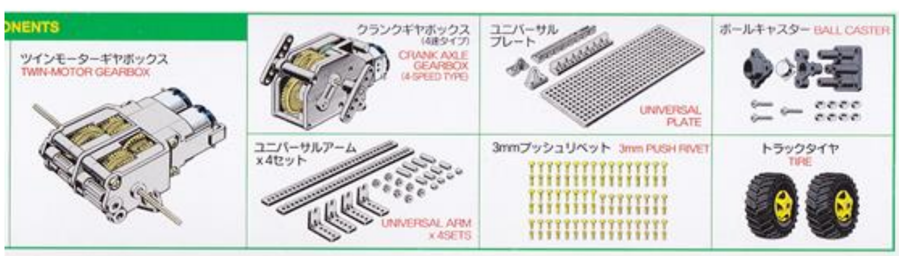

Figure 1. Basic development kit of TAMIYA Inc. Remote Control Robot Construction Set

LPCXpresso1769

Figure 2. Microcomputer development platform

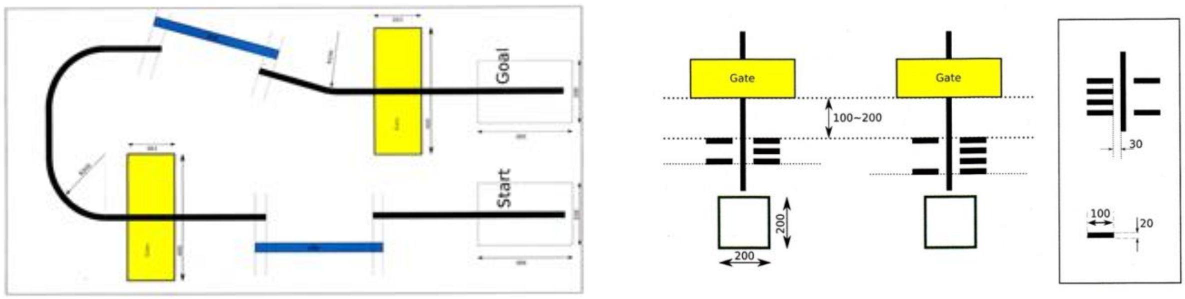

Figure 3. A sample course shown at the guidance in 2017

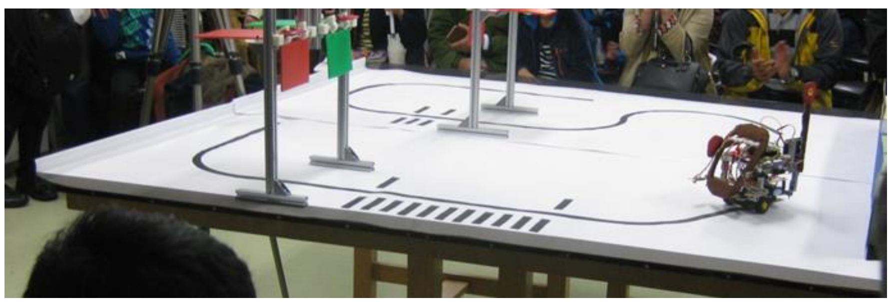

Figure 4. The actual course used in the final round of the contest in 2017

Figure 5. Robots entered in 2017 contest

STUDENT MOTIVATION

According to similar analysis on the effect of learning DE(digital electronics) by doing approach by Siong and Thow from Nanyang Polytechnic (Siong, G.E.and Thow, V.S. 2017), we used the Intrinsic Motivation Inventory(IMI) to evaluate the effect of this PBL program on students' motivation. Motivation is based on Self-determination Theory (Ryan & Deci, 2000) and is related to various activities such as target setting, planning and designing and/or execution of projects and plays an important role in any learning program. The IMI developed by Ryan (1982) and his colleagues from the Rochester Motivation Research Group is a multidimensional measurement device intended to assess participants' subjective experience related to a target activity in laboratory experiments. It yields six subscale scores and has been widely used in studies related to intrinsic motivation and self-regulation. We adopted the same expression but the words "digital electronics" were substituted with "developing a robot" in 45 items corresponding to 6 subscales used by Siong and Thow and translated into Japanese. Students were asked to describe their experience on a Likert scale from 1 (not true at all) to 7 (very true).

We think that the IMI enables quantitative evaluation of the effect of this program on students' motivation. The 45 items for 6 subscales are shown in Table 2. Interest/Enjoyment, Perceived Competence and Effort/Importance are related to students motivation toward the activity. Value/Usefulness is an aspect that is related to one's internalization of an experience. Pressure/Tension is theorized to be negative predictor of intrinsic motivation, and

Relatedness is used in studies having to do with interpersonal interactions or friendship formation.

The same survey was issued to 2 groups of students, IE4 is the group that finished this PBL program a few months ago, and IE5 completed the same program last year. The average scores for each subscale and standard deviations are shown in Table 4. Younger students answered that they enjoyed the program very much whereas senior students scored their enjoyment lower. We might conclude that group IE4 evaluated the program in a more subjective manner with sensory impressions, and group IE5 answered based on a slightly more objective point of view.

Overall, the items in Effort/Importance subscale received high scores and Value/Usefulness received the highest average score in this survey. Perceived Competence was relatively low and Pressure/Tension had the lowest score. However, the expression of each sentence in the Pressure and Tension scale seems to be ambiguous and the students' selections may depend on how they interpret the items.

Table 3. Selected Subscales of Intrinsic Motivation Inventory

Interest/Enjoyment	Perceived Competence	Effort/Importance
• I enjoyed doing this activity very much • This activity was fun to do • I thought this was a boring activity(R) • This activity did not hold my attention at all(R) • I would describe this activity as very interesting • I thought this activity was quite enjoyable • While I was doing this activity, I was thinking about how much I enjoyed it	• I think I am pretty good at this activity • I think I did pretty well at this activity compared to other students • After working this activity for a while, I felt pretty competent • I am satisfied with my performance at this task • I was pretty skilled at this activity • This was an activity that I couldn't do very well	• I put a lot of effort into this • I didn't try very hard to do well at this activity(R) • I tried very hard on this activity • It was important to me to do well at this task • I didn't put much energy into this(R)
Value/Usefulness	**Pressure/Tension**	**Relatedness**
• I believe this activity could be of some value to me • I think that dong this activity is useful for promoting my interest in learning engineering • I think this is important to do because it shows me how to build, test and package a prototype of developing a robot • I would be willing to do this again because it has some value to me • I think doing this activity could help me to sharpen my thinking and problem solving skills in group works and presentation • I believe doing this activity could be beneficial to me • I think this is an important activity	• I did not feel nervous at all while doing this(R) • I felt very tense while doing this activity • I was relaxed in doing these tasks.(R) • I was anxious while working on this task • I felt pressured while doing these tasks	• I felt really distant to my teammate (R) • I really doubt that my teammate and I would ever be friends (R) • I felt like I could really trust my teammates • I'd like a chance to interact with my teammates more often • I'd really prefer not to interact with my teammates in the future (R) • I don't feel like I could really trust my teammates (R) • It is likely that my teammates and I could become friends if we interacted a lot • I feel close to my teammates

Note: The item marked (R) are negative statements. To calculate the item score, subtract the item response from 8.

Table 4. Results of Survey using IMI

IMI Subscales	IE4(35)		IE5(29)	
	Average	Standard Deviation	Average	Standard Deviation
Interest/Enjoyment	5.30	1.56	4.76	1.62
Perceived Competence	4.32	1.51	4.07	1.45
Effort/Importance	5.16	1.41	5.06	1.41
Value/Usefulness	5.37	1.44	4.95	1.48
Pressure/Tension	3.90	1.78	3.83	1.64
Relatedness	4.61	1.65	4.51	1.71

DISCUSSION

We introduced the PBL program called Intelligent Electronic Production program to foster engineering thinking of students. The IMI subscales were used to evaluate students' motivation on this program and to capture how they had felt about the activity in this program.

From detailed results of the survey using IMI, we could see the items "I think doing this activity could help me to sharpen my thinking and problem-solving skills in group work and presentation", "I believe doing this activity could be beneficial to me," and "I think this is an important activity" in the subscale Value/Usefulness were marked higher than others. IE4 said they enjoyed doing this activity very much. On the other hand IE5 denied the item "I thought this was a boring activity (R)," so both groups seem to have worked this activity with certain interest at least. Relatedness might indicate a typical feature of college students. One feature at colleges of National Institute of Technology is that each department has only one class at each grade level. Consequently about 40 students have been studying together for 5 years in the same class. The students have been close to each other for the last three or four years. Most of the students could assume their own role in the group quite naturally and accept the manner of putting the right person in the right position.

Analysis of the IMI survey results suggests that most of students think the program was useful and motivated them to learn engineering. On the other hand, they think their skills were insufficient to complete this program without help.

We took another survey asking students about subjects that they had considered useful for this project work. NIT colleges adopted the spiral-shaped curriculum style that offers many lectures followed by related exercises or experiments and basic course lectures followed by advanced course lectures. We obtained answers from 49 of IE4 and IE5 students. The majority of students (77%) answered the microcomputer basic, advanced I, and II lesson were useful. Three-fourth of students (75%) said the electric circuit (basic, and advanced) was useful, and 42% answered electronic circuit basic, advanced A, and B, 44% chose programing basic, advanced and applied, and 27% voted for fundamental experimentation. These results indicate that this program is well designed to integrate students' knowledge obtained from various lectures and exercises taken previously.

Some of students were also interviewed about the most useful experience they obtained from this program. They emphasized the usefulness of getting to know the reality of engineering work such as what will exactly happen if too much current flows into a microcomputer or electronic device, why they should not apply higher voltage than the acceptable range and/or also the importance of solid connection between cables.

The teachers who organized this PBL program observed that students were more confident after completing the program and applied the valuable experience obtained from this PBL program to their graduation research projects. However setting a proper theme consisting of various levels of challenges is still a big problem to the teaching staff. It is highly expected that the teaching staff should respond properly to a variant of unique challenges with different and often multiple causes. Continuing this PBL program more effectively is certainly a big challenge for us.

In order to reach any concrete conclusion if this PBL program does foster students engineering thinking, we may need to conduct a similar survey of graduates already working as engineers. It is hoped that those valuable experiences of the students will be viewed equally useful to their careers as engineers.

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BIOGRAPHICAL INFORMATION

Nahomi M. Fujiki, Pd.D. is a Professor in Dept. of Intelligent Electronic Systems at National Institute of Technology Sendai College. She is promoting various international exchange programs for students including the long term overseas internship. Her current research focuses on Layered Neural Networks to Deal with Big data.

Kazutaka Baba, Ph. D. is a Professor in Department of Intelligent Electronic Systems and the Deputy President at National Institute of Technology, Sendai College. His current research focuses on Development of Optic Experimental Educational Tools

Tadayuki Hayashi**,** Ph.D**.** is a Professor of Intelligent Electronic Systems and Advanced course of Information and Electronic Systems, and the Vice President of Research and Industrial collaboration at National Institute of Technology, Sendai College, Japan. His current research focuses on Development of High-resolution Magnetic Field Detectors using Ultrahigh-sensitivity Magnetic Sensors

Yasuhiro Kashiwaba, Ph.D. is a Professor in Dept. of Intelligent Electronic System and Advanced course of Information and Electronic Systems at National Institute of Technology Sendai College. His current research focuses on Preparation of Electronic Devices using Zinc Oxide

Koji Kawasakii Ph.D**.** is an Associate Professor in Dept. of Intelligent Electronic Systems at National Institute of Technology, Sendai College, Japan. His current research focuses on Semiconductor Optical Devices

Senshi Nasu, Ph.D**.** is a Professor and the Head in Dept. of Intelligent Electronic Systems at National Institute of Technology, Sendai College, Japan. His current research focuses on Image Processing, Acquisition and Displaying Technologies and the Application

Mio Sakuma, Ph.D. is an Associate Professor in Dept. of Intelligent Electronic Systems at National Institute of Technology, Sendai College, Japan. Her current research focuses on Development of Speech-hearing Therapy Supporting Systems.

Shigeyuki Seki, Ph.D. is an Associate Professor in Dept. of Intelligent Electronic Systems at National Institute of Technology, Sendai College, Japan. His current research focuses on Production of ITO Thin Film and its Application.

Jun Sonoda, Ph.D. is a Professor in Department of Intelligent Electronic Systems at National Institute of Technology, Sendai College. His current research focuses on Development of Electromagnetic Wave devices with High-accuracy and Large-scale Numerical Simulation

Takatoshi Suenaga, Ph.D. is an Associate Professor in Dept. of Intelligent Electronic Systems at National Institute of Technology, Sendai College, Japan. His current research focuses on Development of Human Interface Technology

Tetsuya Ooizumi, Ph.D. is a Professor in Dept. of Intelligent Electronic System at National Institute of Technology Sendai College. His current research focuses on Developing Electric Vehicle Systems to Drive Much Mileage

Takahiro Yonamine, Ph.D. is a Professor in Dept. of Intelligent Electronic System at National Institute of Technology Sendai College. His current research focuses on Development of Speech-hearing Therapy Supporting Systems

Corresponding author

Dr. Nahomi M. Fujiki
National Institute of Technology, Sendai College
4-16-1, Ayashi-chuo, Aoba-ku, Sendai
JAPAN, 989-3128
81-22-391-5570
fujiki@sendai-nct.ac.jp

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AI ASSISTED ADVISING FOR GROWTH OF UNIVERSITY STUDENTS

Takayuki Fukuda, Toshiaki Izumiya, Shinji Takashima, and Shoji Takechi

Kanazawa Institute of Technology

Akane Araki

Joetsu University of Education

ABSTRACT

This paper introduces a new advising system based on datamining and AI technology to boost a rapid and steady growth of individual students. The implemented system gives students useful advices about university life, regular curriculum, and extracurricular activities to change their mindset and behaviors for learning. Especially, we believe that combination of regular curriculum and extracurricular activities is significant for university students because the both are mutually complemented to realize the CDIO cycle. Kanazawa Institute of Technology has electric archives of 15,000 graduates' e-portfolios, and we used the records to counsel each student individually. We actually implemented two kinds of advising systems: one is a datamining system for supervisors use to give advice, and the other is AI advising system that student use for themselves. We tested the efficacy of the systems, and got the positive results.

KEYWORDS

Student growth, Advice, Learning support, Datamining, AI, Standards: 9

INTRODUCTION

Providing better education for diversified students is a common challenge to higher educational institutes. We should support individual students with different experiences, background knowledge, needs and interests (Attard et al., 2010), but we just have limited educational resources. Lately AI (Artificial Intelligence) technology has highly developed, and has employed also in education field (Luckin et al., 2016). This paper introduces an AI application in education to assist advising diversified individual students in KIT (Kanazawa Institute of Technology). The advice derives from electric archives of the 15,000 graduates' records stored in KIT e-Portfolios archives, which contains 1,000,000 datasets including not only their profile but also their thoughts, activities and histories. Therefore, we can give our students individual advice about university life, regular curriculum, and extracurricular activities. We aimed our students to change their mindset and behaviors for learning. We mainly target the “middle-level” students who are have ordinary attitude for learning and middle-level achievement. We aim to give our middle-level students practical advice to change their mindset and behaviors (Regan et al., 2015) via AI based on the graduates data. We don’t target “at-risk” students who will drop out of our university, even if AI can find them in early stages (Marbouti et al. 2016). AI cannot give those students good advice at present, and we believe that they really need practical helps from human advisors. We aim to boost the rapid and steady growth of the individual students by the system (Figure 1).

We actually implemented two kinds of advising systems: one is a datamining system for supervisors called as “Advising Assist System” for human supervisors, and the other is AI advising system that students use for themselves that is called as “Self-coaching System”. Supervisors in KIT can use the Advising Assist System for individual counseling to motivate and support their students. Supervisors can also use the system to make curriculum visualization, and to extract clear portraits of some types of typical students classified by their department, achievement score, or other attributes. Students can use the Self-coaching System to search their specific targets and to motivate for themselves. We tested the efficacy of the systems, and got the positive results.

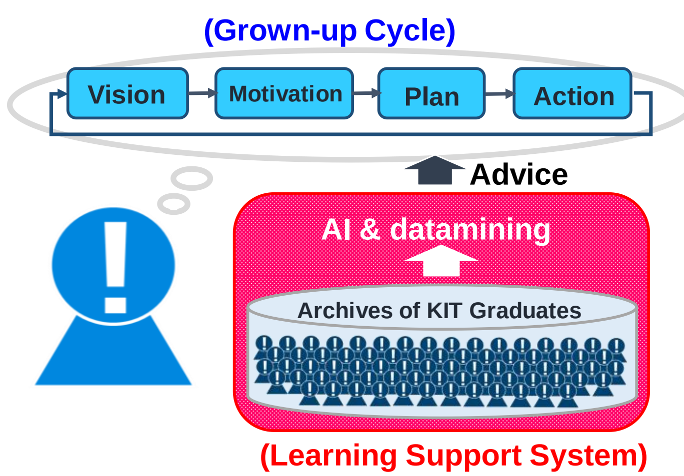


Figure 1. AI supporting coaching

KIT: KANAZAWA INSTITUTE OF TECHNOLOGY

Introduction of KIT

Kanazawa Institute of Technology was established in 1965, and currently has an enrollment of 6,500 undergraduate students and 490 graduate students. KIT provides student-centered learning environment and features Project Design Education in which students identify and solve problems in teams (Saparon et al., 2017). In the education environment, KIT students have experience of finding what people need and embodying their own engineering solution as a prototype. Through a process of experiments, validation and evaluation, they acquire the “innovation skills” that are required of personnel who will play an important role in the global society. The Project Design Education has many affinities with CDIO education (Crawley et al. 2011), so KIT became the first Japanese university to join the CDIO Initiative in 2011. KIT are promoting CDIO in both the regular curriculum and the extracurricular activities. In 2016, we launched an e-syllabus to combine more than 100 extracurricular projects and the regular curriculum for purpose of building overall competence. We believe that combination of regular curriculum and extracurricular activities is significant for our students because the both are mutually complemented to realize the CDIO cycle.

Supervisor System

KIT have a class-based supervisor system, and all of our students can consult their supervisors with no hesitation when they need help. Approximately ninety professors are currently assigned to supervise their class students and the supervisors give them advices about the university life, curriculum instruction, and extracurricular projects. At least once in a semester, every supervisor has an obligation to have face-to-face counseling with the all students individually. Supervisors of the first year students teach the compulsory curricular subject for freshmen, named “Basic Style for Study”, every week in the first and the second semesters. The supervisors give lessons on the mindset of learning and the basic academic disciplines in university to new comers. Every extracurricular project also has one or more supervisors, who are professors or other faculty staffs, to support the student members in each project.

KIT e-Portfolio systems

KIT has already developed KIT e-Portfolio Systems for student’s learning. The e-Portfolio Systems aid our students to drive a grown-up cycle of four phases, which means vision, motivation, plan and action, by recording what they think and behave. In e-Portfolio Systems, students are required to answer some open questions by inputting a certain length of sentences. At present, we are running five kinds of systems: “Basic Style for Study” Class System, “Project Design I & II” Classes System, Career Design System, Self-evaluated Reports System, and Self-evaluated Achievements System.

1) “Basic Style for Study” Class e-Portfolio System
    - This is an e-portfolio system for “Basic Style for Study” class to get actively learning style and keep regular hours of private life in early stage of university life. The first year students input records of personal activities, learning activities, review of activities in the last week and plans for the next week into the system once a week during the semesters. Supervisors return feedbacks about the inputs to their students every week.
2) “Project Design I & II” Classes e-Portfolio System
    - This is an e-portfolio system for both classes of “Project Design I” and “Project Design II”. All students of class record their own class activities and work products. The Project Design I class is coursed in the second semester, the Project Design II in the third semester. Both classes are compulsory curricular subjects, and they are typical embodiment classes of CDIO process.
3) Self-evaluated Reports e-Portfolio System
    - This is an e-portfolio system to input self-evaluated reports for some regular curricular subjects and the extracurricular activities.
4) Career Design e-Portfolio System
    - This is an e-portfolio system for making career path. Students record their past activities before entering KIT, and contemplate their future of ten years from now. From both past and future, they conceive what to do at present regarding learning academic specialties and acquiring professional skills.

5) Self-evaluated Achievements e-Portfolio System
   - This is an e-portfolio system for annual records from the first grade year to the third record at the every year's end. By the way, the fourth grade students do not need to input into the system because they write their graduate thesis as the final work product of university life. The system needs our students to write in records of this year and plans of the next year. The records of this year include goals, past activities toward the goals, achievements, and self-assessments of them. The plans of next year contain next goals, improvable points, and action plans. The number of records of the 15,000 graduates has been up to 420,000 datasets. The archive is used to help supervisors to handle their regular face-to-face counseling with individual student.

The all records of e-portfolio systems are accumulated as archives. KIT has the other archives such as university register of student fundamental profile, records of job getting activities, records of library use, and records of educational center use. For these 10 years, KIT has collected the records of the approximately 15,000 students, and has electrically stored them as numbers, symbols or text format. We utilize these archives as the basic data source for textmining and AI.

ADVISING ASSIST SYSTEM FOR HUMAN SUPERVISORS

We develop two kinds of advising systems: Advising Assist System" for human supervisors and "Self-coaching System" for student. First, we explain the "Advising Assist System" for human supervisors. Supervisors or advisory staffs operate the system to give advice to their students. Second, we will explain the "Self-coaching System" in the next section.

The assisting system for human supervisors aims to support mainly the ordinary or middle level students. We assure that high performing students successfully employ the educational environment to boost their growth, with least advice. In addition, we are sure that low-level students, who are likely to drop out, are sufficiently given generous support and help. On the contrary, middle level students are not usually self-motivated and are given much less support than low-level ones. The number of ordinary students is much bigger than the ones of high and low level students, and they have the potential to grow rapidly if they gets appropriate advices timely. This is the reason why we set students of middle level performance as target.

The Advising Assist System is essentially a functional textmining tool. The system has two subsystems: database and interface. We can use the archives of the students as mention above. The human supervisors are not only professors but also the other faculty members, for example the staffs of Student Affairs Section, who can access the archives. We use Watson Explorer as an interface between database and human supervisors, and the interface helps to find useful data from huge archive (Figure 2). Watson is a general-purpose AI system developed by IBM, and Watson Explorer is the interface system of Watson.

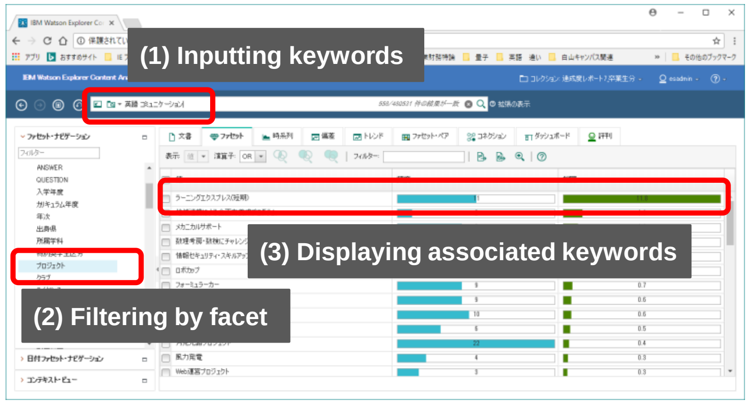


Figure 2. Interface of Advising Assist System for human supervisors

Watson is essentially a question answering computer system capable of answering questions posed in natural language. A supervisor type in words or a phrase, for example “human-powered vehicle”, then the supervisor can find some highly fitted sentences that were written by the graduates who were engaged and committed in extracurricular activities or research related human-powered vehicle.

We clarify three requirements to assist human supervisors to give advice to their students. We explain them in the following subsections.

Searching related information

During individual counseling, students often inquire something with which their supervisor are not familiar. Then the system helps the supervisor in real time to let him or her know about the topic. In this section, we use two databases: university register of student fundamental profile and Self-evaluated Achievements e-Portfolio.

If a student wants to work globally in the future and the student says something about it in the counseling, the supervisor readily types in the two phases “English language” and “extracurricular activities” to find highly matched texts from the database. We actually input these phases into the Watson Explorer, the system indicated the best match topic, “Learning Express”. The Learning Express is a global and social innovation project trying to foster global human resources conducted by some higher education institutes in Southeast Asia (Learning Express, 2018). We also get some useful contexts from the archives of some graduates who participated the project when they were undergraduates. Then the advisor can give some advices to the student as follows:

- One graduate was a project participant once held in Indonesia, and he felt it is very important to take care of each own health in foreign countries.
- The other graduate studied English very hard to get high score of TOEIC (Test of English for International Communication) before going into the project, and she wanted to make her career path to work for a global company

Even if a supervisor does not know the project much or at all, the supervisor can immediately give some valuable and detailed advices to the student in the counseling.

Visualization and extracting keywords

Not all supervisors are necessarily knowledgeable about the curriculums of all departments or the extracurricular activities in KIT. Visualization of curriculum (Mima, 2006) and extracting keywords are very helpful for supervisors. Viewing visualized relationships of keywords, students also understand easily what are significant to learn. The texts from syllabus are available to make visualization such as co-occurrence network. We use the texts of brief summary and behavioral objectives in KIT e-Syllabus. In this section, we analyze and depict some examples by the free datamining software KHCoder (KHCoder, 2018). Figure 3 depicts an example the co-occurrence network of curricular subjects for the first year students in Mechanical Engineering Department. The most appeared keyword is “machinery”, but the centered keyword is “mechanical parts” that has the highest medium centeredness. This can be explained that the students learn about mechanical parts in basic dynamics of mechanism and draw them in the mechanical drafting classes. We find that the centered keywords of the second year’s curriculum is “thermal” and “mechanical property”, and the ones of the third year are “theory”, “method”, and “calculation”. The transition of centered keywords may indicate that the contents of the curricular subjects become more general and more sophisticated as student grade advanced.

Profiling Typical Students

We can find some features of students group such as typical attributes, mindsets, behaviors and growing paths. In this section, we try to find the differences between ordinary students and excellent ones. We define ordinary student as having middle-level QPA scores and participating no extracurricular activities. We also define an excellent student as a student who has high QPA scores and gets involved extracurricular activities as well. By the way, QPA (Quality Point Average) is a system of assessing a student's performance in KIT, and very similar system to GPA (Grade Point Average). In this section, we use two databases: university register of student fundamental profile and Self-evaluated Achievements e-Portfolio. We analyze linguistic dependency parsing from predicative words to nouns.

We analyze each departments, and explain the case of students of Mechanical Engineering Department in this subsection. The ordinary students have the features as follows (Table 1):

- They worry most whether they can earn their course credits for graduation
- They tend to be satisfied as long as they have average credits of GPA

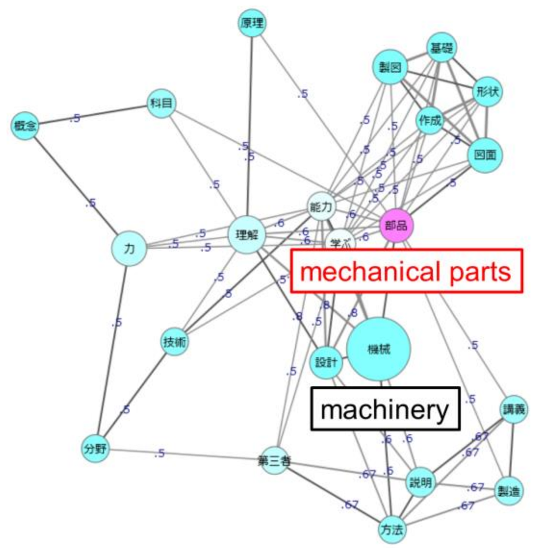


Figure 3. Co-occurrence network of syllabus

- They make an effort to keep regular hours in their life
- Some of them work part-time job for money in their spare time

On the other hand, the excellent students of Mechanical Engineering Department have the features as follows (Table 2):

- They always keep in mind to maintain their high QPA score
- They always try to finish their homework and assignments at a high quality level, and finish the tasks before deadlines.
- They are willing to keep regular hours in their life
- They often visit some learning help centers of KIT, and try to solve immediately their questions in lectures
- They dedicate much time to their extracurricular activities

The results in the tables do not seem correlative words because not every correlative pair consists of two words in English language. Nevertheless, the original correlative pair described in Japanese language are all composed of only two words. The values in the tables mean correlation values that are calculated as the amount of uniqueness of the high frequency of the words pair as compared to other pairs (Zhu, et al., 2014).

Table 1. Correlative words from the records of ordinary students

Inquiry	Top Highest Correlation	Value	Second Highest Correlation	Value
total	earn … course credits	1.3	review … lessons	1.3
next target	be … goal	5.1	not fail … class	4.7
self-evaluation	achieve … goal	8.9	fail … class	7.3
for improvement	get … sleep time	8.0	have … task	7.4
daily practice	be satisfied … situation	12.8	be bad …situation	10.2

Table 2. Correlative words from the records of excellent students

Inquiry	Top Highest Correlation	Value	Second Highest Correlation	Value
total	participate … extracurricular activity	3.5	study further … in graduate school	2.2
next target	do both … at the same time	3.5	master … skill of technology	4.2
self-evaluation	achieve … goal	6.6	keep … high score	4.0
for improvement	manage … time	10.1	get up … early in the morning	5.5
daily practice	submit … before deadline	8.9	deliver … task	7.3

Results and Discussion

We conducted tests to verify the effectiveness of the system. Two volunteer professors who are in charge of class supervisors used the system for the individual counseling with ten students respectively in October 2017. The results and feedbacks from the two professors and the twenty students indicated that the counseling with the system did not give more improved advice than before. We think that the disappointing result is mainly caused by high counseling skill of the professors. The two professors have high skills of learning support, and they hardly need the help from the system. The students therefore felt no differences of the advice between with and without the system.

Then we conducted the second test in the preparation of KIT Stakeholder Meeting in December 2017. The KIT Stakeholder Meeting is one kind of speech contest in which students make short public speaking about their own growth toward people of local corporates and communities. Thirty students made speech in 2017, and seventeen supervisors of faculty staffs supported them. The supervisors made man-to-man discussions several times, and gave advices to brush up the students' speech. We used this opportunity, and the twenty-six students and five supervisors cooperated with our test. We carried out questionnaire surveys twice, before the first discussions and after the last ones. We found the significant differences of the students' self-evaluations that indicated the growth of capabilities and skills. We also got positive feedbacks from some supervisors.

SELF COACHING SYSTEM

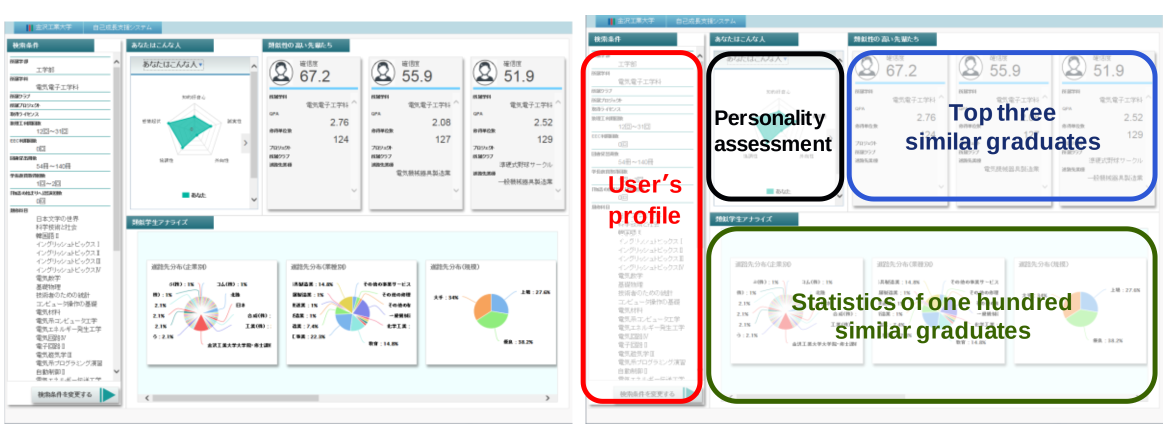
An academic adviser with artificial intelligence, referred to as "Self Coaching System", has been in service in November 2017. Students can search over one million datasets in the archival records of KIT graduates from the e-portfolios databases to select a student with a similar academic background, and they can get appropriate advice based on the data taken from the record. The AI system can provide students with timely advice with regard to their choices regarding curriculum and extracurricular activity. This system is implemented based on IBM Watson, and is applied a machine learning technique developed by IBM.

A student logins the system, then the system opens the interface window (Figure 4). The interface of the KIT has four sections: user's profiles, personality assessment, profiles of top three graduates who are very similar to the user, and statistics of the one hundred graduates who are similar to the user.

1) User's profile section displays the information including department, participating extracurricular activities, holding certifications, number of the educational centers use, number of lending books from the library, number of getting the incentive award of KIT,

choice of university courses, number of earned credits, GPA score, percentage of class attendance, hometown, job after graduation, and so on. This section is available for not only displaying a user's profile but also setting search conditions in the following 3) and 4).

2) Personality assessment section depicts a pentagon radar chart of personality judged by records of user's behaviors from "Basic Style for Study" class e-Portfolio database. The radar chart has five metrics that indicate intellectual curiosity, conscientiousness, extraversion, agreeableness and neuroticism. Neuroticism in the chart means stability of emotions of a user. Each value of metrics is assessed by five grade in this system.
3) Top three similar graduates section provides three graduate icons, who are the most similar to the user, with accordance rate between the user and each of them. A user clicks the icon, and then a window of detailed profile of the graduate opens. The opened window indicate a comparison of personality assessment, and records of the graduate's Self-evaluated Achievements e-Portfolio. The records of very similar graduates will suggest a role model to the student. If a user changes values of attribute in the user's profiles section, the selected graduates will change according to the change. A student therefore can get wise to approach his or her future vision what to change or improve about them by simulating. Needless to say, we meticulously mask the detailed personal information not to identify an individual graduate.
4) Statistics of the one hundred similar graduates section depicts some pie charts about jobs and one list of certifications. The pie charts of jobs displays industries or company sizes of one hundred of graduates. The list of certifications indicates the exams they passed, so it means the recommendation list of certifications to deserve to get. This section gives useful information to make a professional career path.



(a) Opening screen (b) Layout of sections

Figure 4. Interface of Self-Coaching System

We also are developing a chatbot to give advice to our students in a style of casual conversation. The chatbot works based on Self-Coaching System and Self Advising Assist System. We are uniquely trying to give helpful advice from archive of great persons' saying via the Chatbot, and our students will have fun and get encouraged.

Results and Discussion

We conducted the trial event of experience of the Self Coaching Systems including the chatbot from August 1 to August 4, 2017, prior to starting the formal operation of the AI system in November 2017. Approximately 350 students experienced the AI systems. We conducted a questionnaire survey and interviews, and forty-four percent of 144 questionnaire respondents were proven to be satisfied with the system.

CONCLUSION

We implemented the AI assisted advising system for university students. The Advising Assist System helps human supervisors or advisory staffs to counsel individual students and motivate them. The system assist for supervisors' counseling to give advice in which individual student have an interested. The system also work to make curriculum visualization, and to extract clear portraits of some types of typical students classified by their department, achievement, educational score, and other attributes. The system is especially expected to counsel the ordinary student who has not clear target in near future. The Self-coaching System helps student to search their specific and detail targets and to motivate for themselves. The advice derives from electric archives of the 15,000 graduates' records stored in KIT e-Portfolios, which contains 1,000,000 datasets including not only their profile but also their activities and histories. We aim to boost the rapid and steady growth of the individual students by the systems.

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BIOGRAPHICAL INFORMATION

Takayuki Fukuda is the Associate Director at the Office for Industry-University Collaboration of Kanazawa Institute of Technology, Kanazawa, Japan. He supports innovation projects by industry-university collaboration. He is an assistant leader of AI campus project of KIT, and he is mainly in charge of introducing the system.

***Toshiaki Izumiya*, **Ph. D. is the Associate Managing Director of Headquarters Office of KIT. He is the leader of AI campus project of KIT.

Shinji Takashima is the System Manager at Center for Information Services & Processing of KIT. He is an assistant leader of the AI campus project of KIT, and he is mainly in charge of developing the system.

Akane Araki is a graduate student of Joetsu University of Education, Niigata, Japan. She was an undergraduate student of KIT till March 2018, and she contributed the surveys in this research.

Shoji Takechi, Ph. D. is a Professor in Management System Department at KIT. He is also the Director of Co-Creation and Innovation Laboratory for Local Communities of KIT. His current scholarly activities focus on the datamining of actual social data.

Corresponding author

Dr. TAKECHI Shoji
Kanazawa Institute of Technology
7-1 Ohgigaoka Nonoichi Ishikawa,
921- 8501, Japan
81-76-248-1100
takechi@neptune.kanazawa-it.ac.jp

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PRACTICE AND EVALUATION OF STATISTICS AN INTRODUCTORY LECTURE ON PEER INSTRUCTION

Tetsuya Taniguchi, Tomoshige Kudo, Hidetaka Yamaoka and

Kanazawa Institute of Technology

Makoto Nishi

Kanazawa Institute of Technology

ABSTRACT

"Basic knowledge of mathematics and science and expertise as a technician" is cited as one of "knowledge, skills, and attitudes required for engineers who will be responsible for the future" in CDIO syllabus, and CDIO Standard 8 Active Learning ", which is a framework for training engineers consisting of 12 standards. We have practiced introductory statistics lecture using Peer Instruction (PI) which is one of active learning methods. PI has many conceptual problems developed in physics and many practical examples. In mathematics, however, conceptual problems are extremely small, so we have gathered together among faculty members to analyze the results of implementation of PI, develop and improve mathematical conceptual problems, and strive to improve teaching ability among teachers (CDIO Standard 10). Also, as a feature of PI, it is said that general teachers can easily practice active learning in regular classrooms, so we expect to contribute to the further development and popularization of CDIO.

KEYWORDS

Active Learning, Peer Instruction, Mathematical Concept Question, Standards:8, 10.

INTRODUCTION

At recent universities, the shift from "one way class" to "interactive class" based on the traditional lecture form is progressing. "Interactive class" is a form of class focusing on the interaction between teachers and students and students. Examples include "workshop type lesson" By Laws (1997). And "peer instruction (PI)" by Mazur (1997). PI is a kind of active learning type lesson form incorporating discussion between students. According to the words "peer: student-to-student" and "instruction: teach each other", teaching among students is the essence of PI, and it is characterized that students themselves actively make corrections of misunderstandings and deepening concept understanding. Teachers present "conceptual problems" to students and urge students to discuss. PI and conceptual problems have already been achieved in physics subjects. We are expected to develop mathematical conceptual problems and lead students to a more intriguing understanding of mathematical concepts by applying PI. So we started to create mathematical conceptual problems and introduce active learning by Peer Instruction (PI) in mathematics priming subjects (CDIO Standard 8). Also, at the end of the term, faculty analyzes PI practice results, create and improve conceptual problems, and strive to improve teaching ability among teachers (CDIO Standard 10). In the small sentence, report, part of the practical result in the introductory statistics lecture, which the first author was in charge.

USE OF CLICKER, PROCEDURE OF PEER INSTRUCTION

An overview of the clicker system used in this practice is shown in Figure 1. Distribute Clicker (remote controller) to each student. The teacher PC equipped with the receiver which receives the signal from the clicker has three roles:

- Role to present a problem and answer choices to students at the projector,
- Role of collect answers from students,
- Role to feed back the aggregate result of answers from the projector.

Although the use of clickers is not essential in PI, there are advantages such as aggregation of students' answers and easier analysis of lesson effect by using Clicker, which is compatible with PI (described later). The procedure of PI in this practice is as follows (1) to (5). We will call this series of procedures "unit" in the lower case. The execution time of one unit was about 10 to 15 minutes, and the number of execution units per class (90 minutes) was generally within 4 to 5 pieces.

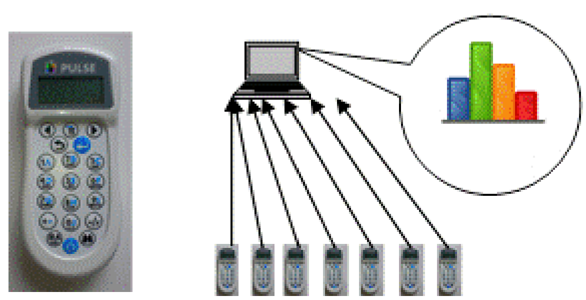

Figure 1 Overview of clicker system

(1) Explanation of learning materials by writing on blackboard
(2) Presentation of answer choices (before discussion), "voting" using clickers, feedback of counting result
(3) Discussion among students on answer choices
(4) Re-presentation of answer choices (after discussion), "voting" using clickers, feedback of counting result
(5) Presentation and explanation of correct answer

In PI, the discussion in (3) is important, and the understanding of students changes dramatically before and after that. The situation is immediately transmitted to the entire classroom at (2), (4). In the clicker system, it is possible to instantly totalize and display the distribution of students' responses. It is also a great advantage that students can understand the degree of understanding of students in (2) and (4) in this way and it becomes easier for teachers to develop lessons in accordance with their degree of understanding.

Although the teacher is involved in the teaching with the writing on the blackboard of (1) and the presentation / explanation of the correct answer of (5), the teacher does not intervene in the content of the discussion between (3) students, leaving it to the discussion among the students. However, we advised on appropriate discussions such as "Please state the basis of your answer and let the other party understand" and devised so that students can discuss it smoothly.

Presentation of alternative answer choices in (2) and (4) presents the same problem. We prepared a problem asking conceptual matters. If understanding degree in (2) is low, learn deeply in the discussion of (3) and try to formulate the concept of mathematics. If it is judged that the degree of comprehension of (2) is sufficiently high, omit (3) and (4) and proceed to the next problem.

ADVANTAGES OF CLICKER SYSTEM IN PEER INSTRUCTION

Although the use of clickers is not necessarily required in PI, clickers have three major advantages:

(1) Immediate nature of aggregation / feedback:
The clicker system can instantly tabulate the answers of students and can immediately present the response distribution status of all the members on a slide so that the classification result can be shared throughout the class. It is also interesting for teachers, as students receive surprising responses, such as when a student answers are divided.
(2) Traceability of individual answer history:
Since each clicker can be associated with an individual student, the response history for each individual can be saved. Therefore, it is also possible to perform detailed comparative analysis with changes in answer patterns for individuals, calculations in regular tests, and description problems.
(3) Anonymity of personal answer:
"What you answered" is not known to identify students, so it is easy to answer honestly. Therefore, it is considered that more accurate data can be collected by clicker system.

IMPLEMENTATION RESULT

Introductory lecture on statistics at the Kanazawa Institute of Technology in charge of the first author, PI and clicker were introduced from the first semester 2016 and urged students to learn each other. The answer choice problem used in this practice was developed by the authors jointly.

Problem example
Figure 2 asks the shape of the graph of the distribution function $F(x) = \sum_{t \le x} f(t)$ from the probability function $f(x)$ of the discrete probability distribution and contains the conception of "to accumulate probability values" as a component. Since the value in Figure 2 is monotonically increasing, the correct answer is No. 3. The top row of the table is the distribution of responses before the discussion and the bottom row is the distribution of responses after discussion.

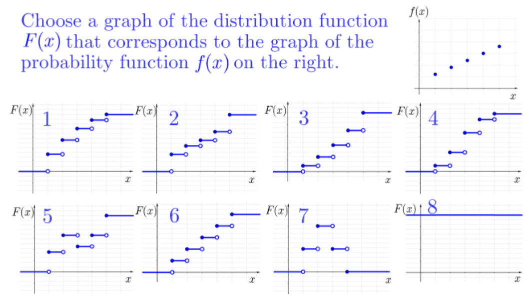

Figure 2. Answer choice problem and answer situation (probability distribution function)
Note: The problem slide is referenced in Taniguchi, Nishi, Kudo, & Yamaoka (2017)

Table 1. Results of Figure 2.

Answer number	①	②	③	④	⑤	⑥	⑦	⑧
Before discussion	5.5%	0.0%	**63.6%**	3.6%	0.0%	25.5%	0.0%	1.8%
After discussion	3.6%	1.8%	**87.5%**	0.0%	1.8%	3.6%	0.0%	1.8%

RELEVANCE TO FINAL EXAMINATION

Data comparing the results of the final examination of the statistical introductory lecture (lecture until the first step of the inferential statistics) that the first author was responsible for the first semester of 2015 (before introduction of PI) and the first semester of 2016 (after introduction of PI) quoted from the reference Taniguchi, Nishi, Kudo, & Yamaoka (2017)
a) Probability calculation Trend of correct question rate: 46% → 65%
b) Reverse lookup the normal distribution table Problem Trend of correct answer rate: 23% → 84%
c) Finding the rejection region of t-test Trend of correct answer rate: 10% → 25%

The calculation of the two-tailed t-test showed that this change was statistically significant at the p = 0.05 level for b) and c), and the correct answer rate is considered to be improving (Software used: Microsoft Excel 2010 analysis tool "t-Test: two-sample test assuming that variances are not equal ").

Next, we compare the final examination of the first semester of 2016 in the first year of PI introduction and the final examination the first semester of 2017. Both classes are in charge of the same grade of the same undergraduate division, in particular the number of questions and the range of examinations for final examinations are aligned in both academic years, and the textbooks and learning process used are the same. The average of the final examinations of both years was higher in 2017. The calculation of the two-tailed t-test for the final examination results of both years showed that this change was statistically significant at the p = 0.05 level. About this result, we believe that it is because the explanation by writing on the blackboard after class start and the selection order of problem slides are made smoother.

Table 2. Comparison of final examinations (previous term of 2016 · 2017)

t-Test:Two-Sample Assuming Unequal Veriances		
	2016	2017
Mean	65.44262295	72.38596491
Variance	334.384153	357.9197995
Observations	61	57
Hypothesized Mean Difference	0	
df	115	
t Stat	-2.024633368	
P(T<=t) one-tail	0.022610852	
t Critcal one-tail	1.65821183	
P(T<=t) two-tail	0.045221704	
t Critical two-tail	1.980807541	

(Excel 2010 analysis tool: test with two specimens assuming that t-test variance is not equal)

CONCLUSION, FUTURE PROSPECTS

We have started to develop mathematical conceptual problems and peer instruction in mathematics priming subjects. We actually carried out peer instruction using Clicker, and got a response history of the student. Furthermore, we have conducted response survey on the likes and dislikes of mathematical physics and mini tests on probability statistics at the first lesson and last lesson in each semester to secure answer data before and after class.
In the future, I would like to continue teaching improvement activities between teachers (CDIO Standard 10), progressing active learning by PI, developing mathematical conceptual problems, and contributing to further development and dissemination of CDIO through our efforts.

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BIOGRAPHICAL INFORMATION

Tetsuya Taniguchi, Doctor of Science, Ph. D. is a Lecturer in Academic Foundations Programs at Kanazawa Institute of Technology. His current research focuses on Peer Instruction lecture in mathematics and algorithms in algebraic number theory.

Tomoshige Kudo, Doctor of Science, Ph. D. is a Lecturer in Academic Foundations Programs at Kanazawa Institute of Technology. His current research focuses on Peer Instruction lecture in mathematics and physics. He develops self-adaptive e-learning website, ‘‘KIT Physics Navigation’’, and researches foundation of quantum mechanics.

Hidetaka Yamaoka is an Associate Professor in the Mathematics and Science Academic Foundations Program at Kanazawa Institute of Technology. His current research focuses on mathematical concept test in the engineering education and on application of differential geometric technique in physical phenomenon and engineering problems.
Kanazawa Institute of Technology

Makoto Nishi is a Professor in the Mathematics and Science Academic Foundations Program at Kanazawa Institute of Technology. His current research focuses on flip teaching and developments of educational contents in STEM education.

Corresponding author

Tetsuya Taniguchi
Kanazawa Institute of Technology
7-1 Ohgigaoka, Nonoichi, Ishikawa 921-8501
Japan
+8176-248-1100
t.tani@neptune.kanazawa-it.ac.jp

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PROJECT PROCESS MANAGEMENT IN A STUDENT-DRIVEN LEARNING ENVIRONMENT

Sanna Määttä, Janne Roslöf, Marika Säisä

Faculty of Engineering and Business
Turku University of Applied Sciences, Turku, Finland

ABSTRACT

“TheFIRMA” is a project-based learning environment in the Information and Communication Technology (ICT) unit of Turku University of Applied Sciences (TUAS), Finland. The project assignments in theFIRMA provide students with an active way of learning new skills and increasing knowledge. In addition, students gain a real-life twist in their studies in terms of real customer projects. Customers of theFIRMA are typically local small or medium sized enterprises in need of a small project related to ICT field. The assignments include, for example, web-development, small testing projects, mobile app prototypes, marketing material design, requirements analysis and even organizing Lego robot workshops for children. When the number of projects and students in the FIRMA started to increase, a more organized structure to handle the situation needed to be established. Since the academic year 2016 – 2017, a course called ICT Services and Projects was harnessed to bring an organized structure into theFIRMA’s operations. In addition, the course integrates project work done in theFIRMA into the curriculum of ICT unit’s degree students. This paper describes how project work in theFIRMA is integrated in the regular curricula of the ICT related Bachelor’s degree programs at TUAS. Moreover, this paper describes the lessons learned and improvements of the ICT Services and Projects course as well as the continuous improvement of theFIRMA’s project process.

KEYWORDS

Learning environment, Learning process, Project-based learning,
CDIO Standards: 3, 5, 6, 7, 8

INTRODUCTION

TheFIRMA is a project-based learning environment at the ICT unit of Turku University of Applied Sciences (TUAS). TheFIRMA is student-driven, meaning that it has a student CEO managing operations, student project managers managing projects, a student marketing manager and even student system administrators taking care of computers and networks. Moreover, students are involved in real customer projects (Määttä et al., 2016; Määttä et al., 2017; Roslöf, 2016; Säisä et al., 2017). The FIRMA offers students an active learning environment with various learning opportunities covering all parts of the C-D-I-O core (Crawley et al., 2007). Figure 1 illustrates various projects and activities in theFIRMA.

Figure 1. TheFIRMA's projects include workshops, Lego robot building camps and virtual reality games. Time management is essential.

TheFIRMA was established 2015 by combining previous project-learning environments of the ICT unit of TUAS together (Määttä et al., 2016; Säisä et al., 2016). The learning environments that preceded theFIRMA had relatively small number of students at a time. Therefore, the management and organization of these environments were lightweight and they did not really need a formal project process. This paper presents briefly theFIRMA's project process. Moreover, this paper describes how a course called ICT Services and Projects has been utilized in getting more students to study in theFIRMA and in handling the "big mass" of students.

THEFIRMA BENEFITING LOCAL COMPANIES AND CITIZENS

TheFIRMA does not only benefit our students, it also offers local enterprises various ICT-related projects at an affordable price. Especially, very small enterprises (whose main area of expertise is not ICT, but for example hairdressing, accounting or retail) may not be able to use the services of ICT subcontracting companies but would still need such technical expertise that they do not have themselves. TheFIRMA can offer various services to these entrepreneurs: not only web pages or other technical projects, but also innovation workshops where students innovate for example new marketing possibilities, design new graphical image, or conceive ideas that would help the business to grow or take a leap to digital era.

In general, customers are very understanding of the fact that theFIRMA's projects do have a relatively long schedule in order to enable students enough time to learn not only necessary technical skills, but also soft skills. However, some customers may need a project delivery faster than theFIRMA can offer, or the proposed assignment is outside theFIRMA's scope. Therefore, co-operation with local ICT companies is needed and, sometimes, the customer is handed over to these professionals. Moreover, ICT businesses can present their operations or recruitment needs to theFIRMA students thus finding potential new employers, interns or thesis workers. For example, innovation workshops where students innovate or solve problems for companies offer them a better view to the students’ skills so they can use the event as a recruitment opportunity in addition to regular job interviews.

TheFIRMA offers services also to private citizens. Citizen’s helpdesk offers free support in using computers, tablets or smartphones. Students working in the citizen's helpdesk also fix computers (for example remove viruses, install new software or update computers). Help desk is managed by student project manager who is a TUAS degree student. The helpdesk employees are mainly local vocational college students who are doing their internship.

THEFIRMA BENEFITING STUDENTS

To students, theFIRMA offers an active way to learn new skills and to gain credits. In addition, students benefit a great deal when working in theFIRMA. Participating in real customer projects seems to increase students' motivation towards the topic compared to working on (even relatively similar) assignments on a regular course. Moreover, for student project managers the real customer projects cause a very different pressure to do their job compared to regular course assignments. Figure 2 shows a student project manager at work in theFIRMA premises.

In theFIRMA’s projects, students have the opportunity to learn communication skills with real customers, time management skills, team-working skills, problem-solving skills and even language skills due to working in a multicultural environment. In addition, students learn how to orient newcomers into theFIRMA practices and projects, manage customer relationships, assess the quality of their own work and peer review fellow students’ work.

As well as soft skills, students also have the possibility to deepen and broaden their technical knowledge. Students have the opportunity to work in various projects for various customers sometimes learning quite deep skills from the used tools and technologies. Especially student system administrators, who maintain theFIRMA’s networks and computers, have the opportunity to work in such a realistic environment that would be hard to replicate on a regular course. Figure 3 depicts students working in theFIRMA.

In theFIRMA's projects, students start from conceiving the idea, continue to design and implementation phases and in several projects they can even be part of the operation phase. For example, administrating the computers, servers and networks in theFIRMA premises or giving short-term maintenance or training for customers cover the operation phase of CDIO. Therefore, theFIRMA fulfills all the CDIO framework's phases and produces skilled students who can handle the complex requirements of the working life.

Figure 2. TheFIRMA is student-driven, thus giving project management responsibility to student project managers.

Figure 3. Students work in project groups in real customer projects.

THEFIRMA'S PROJECT PROCESS - ENABLING GROWTH

The purpose of a project process is to improve the quality of work. Often this aim is twofold: First, how to deliver customers good quality projects and second, how to increase the staff's knowledge. As theFIRMA operates like a small ICT company, it also has a project process. However, as theFIRMA is not a real company but a learning environment at TUAS, in addition to quality process we also need a learning process (Määttä et al., 2017). The purpose of the quality process is to provide theFIRMA's customers with good quality projects whereas learning process is used to give students credits and grades thus supporting their professional growth. Students define project specific learning goals at the beginning of each project, track their working hours during the project and at the end of the project assess whether the learning goals were met.

Since theFIRMA was established, the amount of students and projects has grown gradually, thus making several challenges and features of such an environment visible. TheFIRMA operates all year round and does not follow the same schedules of the academic year than regular courses at TUAS. For example, students can start in theFIRMA at any time and they can leave theFIRMA at any time. Moreover, students participate in different number of projects (which start and end at different times) and work different amount of hours getting different amount of credits. Therefore, theFIRMA is like a small company that is constantly in a severe human resources crisis. As we consider this the normal operation mode and even embrace the freedom from schedules of the regular academic year, it does require a good process how to handle this.

Course Tackling Challenges

Harnessing the 15 credits ICT Services and Projects course tackles some of the challenges. Majority of the students in theFIRMA study there within this course, and only a few students stay there longer. Therefore, using the course and its structures for giving credits and grades helps us to manage a larger amount of students. Currently, this course consists of three parts: attending guest lectures and ICT related events, technical certification (Microsoft Technology Associate (MTA) certification) and project work in theFIRMA in customer projects. Attending guest lectures and ICT related events increases students' knowledge about local ICT businesses and enables networking with other students and local ICT companies. Technical certification and project work in theFIRMA aim at increasing students' technical skills.

Students can start the ICT Services and Projects course at any time and finish it within one calendar year. The course has no regular or fixed schedules thus requiring a lot of activity, responsibility and initiative from students. ICT Services and Projects course or theFIRMA in general have very little to do with "normal" classroom teaching. There are many ways to study the course, most project work is done in theFIRMA's projects, but sometimes also in the ICT unit's research projects, in co-operation projects with other universities or in the students own projects (for example, a web site for family business, time management system for a hobby club and so on). It is challenging for theFIRMA's staff members to stay in contact with the students when they are spread in so many projects. Thus, this gives students a lot of freedom but also a lot of responsibility to follow their own progress or contact their teacher in case of problems they cannot solve by themselves.

Course Causing More Challenges

Yet, we noticed several drawbacks in the ICT Services and Projects course's setup during the first implementation of the module. First, some students struggled in the technical certification part. Second, student motivation and professional attitude varied a lot in the project work part. Third, some students were not able to finish the course during one academic year. Thus, students struggling with their technical skills as well as motivation and professional attitude were usually the students who did not finish the course within the planned course duration; and some did not finish the course at all.

Since the academic year 2016 – 2017, the ICT Services and Projects course is offered as a free choice course for all students of TUAS. This gave the course a lot more visibility at TUAS and as a result, the number of students on the course suddenly rose. However, approximately half of the students who started the course never finished it. Students did not seem to know what they signed up for, or maybe they overestimated their skills in time management or underestimated the requirements of the course. Moreover, the nature of the course and theFIRMA's customer projects (that is, freedom comes with responsibility) seemed to surprise many students.

Because so many students (all allocated to customer projects) suddenly disappeared from the course (and from theFIRMA), our human resources crisis did not get any easier. We had to put some internal development projects on-hold in order to properly resource all customer projects. Moreover, as well as teaching staff, also student project managers had to spend (and in some cases: waste) a lot of time to try to reach the students who just disappeared without any notice.

On a regular course, students quitting the course is naturally undesired. However, on a course involving real customer projects students lacking motivation and professional attitude is obviously an even more significant challenge. When some project members do not accomplish their tasks, show up in meetings or just quit the project (even without any notice), student project managers' burden increases and a lot of teacher intervention is required. Moreover, it also puts theFIRMA's project process in test: how do we handle the constant human resources crisis and are still able to deliver theFIRMA's customers good quality projects in time.

Lessons Learned

Due to the challenges on the ICT Services and Projects course, several changes have been made: We now offer more information about the course, have added pre-assignments to test motivation and improved theFIRMA's project process. For example, students are provided with more information about what kind of skills are required from students who choose the course. That is, students who rather sit in classroom or are not yet prepared to take direct responsibility of their own learning or professional growth realize that the course is not suitable for them.

After the first implementation of the course, two mandatory pre-assignments were added. A student is not assigned to any project work before a teacher accepts the both pre-assignments. The pre-assignments test student's motivation, knowledge and time management skills. Moreover, the assignments also make students to think about software project management and the role of a team member in a project. We have noticed that if students are not motivated enough or have limited skills to take initiative, they have difficulties in starting or finishing the pre-assignments. In this case, they would also have difficulties in being productive project members in a real customer project. Hence, well-made pre-assignments predict that students are capable and responsible enough that they can be placed to a real project.

The first implementation of the course also caused several changes to theFIRMA's project process. First, the orientation practices for new students in theFIRMA needed to be revised. Instead of burdening the student project manager to guide newcomers, the student CEO started to orient new students using an orientation checklist tool. We also had to take a more prompt policy into use what comes to students quitting or changing projects. After two failed attempts to reach a student or student not showing up in agreed meetings without an acceptable explanation means that student is not given a third chance. Students were also noted that the ongoing project could not be changed just because "it is not interesting enough". Having a professional attitude towards the "not so interesting" projects is nevertheless valuable skill in working life as well.

CONCLUSIONS AND FURTHER WORK

This paper introduced a project based learning environment, theFIRMA, and how project work is integrated into the curriculum. The FIRMA is a good example of a learning environment that is able to provide active learning opportunities covering all the aspects of the C-D-I-O core model. Moreover, this paper presented lessons learned how to manage students in such a versatile and dynamic environment.

Currently, one part of the ICT Services and Projects course is technical certification, which means that all students on the course have to pass an MTA certification exam. These exams are closely related to ICT subject field and, thus, they easily exclude business or arts students from the course even if theFIRMA projects could greatly benefit from that kind of knowledge as well. In the future, the MTA exam will not be a mandatory requirement on the course.

One of the challenge of the human resource management is that even if theFIRMA's projects do not follow the regular academic year's schedule, majority of students still want to start in theFIRMA in September when the semester starts or in April – May, when their internship period starts. ICT Services and Projects course does allow any schedule and the aim is that the student flow would be more balanced throughout the whole year. So far, this has not happened and it is left as future work to even the peak seasons of the number of participating students.

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BIOGRAPHICAL INFORMATION

Sanna Määttä is a lecturer in the ICT unit of Turku University of Applied Sciences. She holds Doctor of Technology and Master of Science degrees in digital and computer systems from Tampere University of Technology (Tampere, Finland). She is also one of the responsible teachers in theFIRMA, mainly concentrating on developing and improving the quality and learning processes of the FIRMA as well as theFIRMA competence track for third and fourth year students.

Janne Roslöf is a Head of Education and Research (ICT) at Turku University of Applied Sciences. He holds a D.Sc. in Process Systems Engineering and a M.Sc. in Chemical Engineering from Åbo Akademi University (Finland), and a M.A. in Education Science from University of Turku (Finland). He has participated in several national and international educational development assignments. Currently, he is a member of the national Engineering
Education working group of the Rectors' Conference of Finnish Universities of Applied Sciences, as well as the Technology Industry and Services anticipation expert group of the Finnish National Agency for Education.

Marika Säisä is a project manager in the ICT unit of Turku University of Applied Sciences. She holds a Master of Science in Technology degree from University of Turku (Finland). She is responsible project manager in theFIRMA, mainly concentrating on customer relations and mentoring students with customer projects. She has participated in several national externally funded projects. Currently she works as a project manager in Inside the Box and Hot Potato.

Corresponding author

Dr. Sanna Määttä
Turku University of Applied Sciences
Joukahaisenkatu 3
FI-20520 Turku, Finland
+358 40 355 0921
sanna.maatta@turkuamk.fi

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STUDENT-CENTERED LEARNING IN CDIO FRAMEWORK

Antti K. Piironen
Metropolia University of Applied Sciences, Finland

Ann Padley
Centre for Innovation and Entrepreneurship, University of Bristol, UK

Kaisla Saastamoinen
Laurea University of Applied Sciences, Finland

ABSTRACT

This paper explores this intersection between Project-Based Learning (PBL) and student centricity through a CDIO case study called the Digital Wellbeing Sprint. The Sprint gathers multidisciplinary and culturally diverse students for an intensive, multi-day service innovation course where teams work on real-life problems from partner companies or organizations and explore modern tools and methods for co-creation and service design. The partnerships offer a platform for implementing Project-Based Learning which challenges students to explore the live brief from a human-centred perspective, then conceive of and design a potential solution. Successful implementation requires a teaching team willing to embrace a student-centered approach where the teacher's role shifts from 'sage on the stage' to 'guide on the side.' To help facilitate the shift in mindset, organizers have worked to understand the value students experience from this type of learning and identify student-driven Intended Learning Outcomes (ILOs) that work alongside those developed by the educators. This paper gives a brief introduction to how project-based learning was used alongside co-creation and service design to support a student-centered learning environment, describes the results from the latest Sprint, shares key learnings about the implementation, and discusses future development of the concept.

KEYWORDS

Student-centered, Project-based learning, co-creation, intensive course, service design
Standards: 3, 5, 7, 8, 10

INTRODUCTION

Laurea, Haaga-Helia, and Metropolia Universities of Applied Sciences (UAS) formed a strategic alliance to strengthen their competitiveness within Finnish Higher Education Institutes. The universities organized their first joint Professional Summer School (PSS) in 2016 under the name "Digital Wellbeing Sprint" (the Sprint). The Sprint combined Service Design expertise of Laurea, Entrepreneurial mindset of Haaga-Helia, and experiences on

CDIO of Metropolia, which offered a powerful engine to solve real-life multidisciplinary problems (Piironen et al., 2017). The intensive two-week course brought together multidisciplinary teams of undergraduate and master's students to learn about service innovation following the "Conceive Design Implement Operate" model (CDIO 2017) and a focus on student-centred learning.

Students were tasked with solving real challenges from partnering organizations while learning tools and methods for co-creation and service design. In the first week, students explored their challenge by doing field and desktop research to learn about users, the service provider, the business environment, and relevant trends. Teams then conceived ideas for a new service concept and spent the second week on problem-based learning in small groups by iterative prototyping, business model generation, and pitching their newly created concept to the clients. Additional details of the Sprint can be found from Piironen, Haho, Porokuokka, Hirvikoski, and Mäki (2017). The Sprint offers Design-Implement (Standard 5) and Integrated Learning (Standard 7) experiences for the students on an Integrated Curriculum (Standard 3), which was planned and reviewed by the internal and external stakeholders.

A student-centered approach was used in the learning design as its focus on students as active participants in learning and facilitative style of delivery are a natural fit for the CDIO framework. The aim was to empower the teachers and mentors to adopt the role of a designer of learning; partner with students to understand their needs, interests and perspectives; and use these insights as they facilitate the learning experience. The benefits for learners of a student-centered approach include increased motivation, sense of responsibility, and engagement in learning (ESG, 2015; Bovill, 2014).

By embracing student-centricity in a project-based learning environment, the newly formed UAS alliance has worked to further develop the Sprint concept, starting with gaining a better understanding of its own users: the students. To do this, a four-step process was used to iterate the Sprint concept the following year and later published to help other educators to rethink a learning experience using a collaborative, student-centered approach (Padley & Piironen, 2017). This work also went on to support the enhancement of faculty teaching competence for the three Universities (Standard 10). This paper presents our student-centered methodology, how it was implemented in the 2017 Sprint, discusses key findings from the experience, and gives recommendations for the future events.

METHODS

As an educational Research, Development and Innovation (RDI) initiative, the Sprint is intended to be a testing ground for new strategies that will shape the future of Finnish education. Research conducted alongside both the pilot and second implementation of the Sprint has been analyzed to form the basis for this paper.

For the 2016 Sprint pilot, the planning team collected demographic data as well as open-ended responses about students motivations for participation in an application questionnaire. A mid-term survey distributed during the Sprint included a qualitative set of questions allowing for open-ended responses related to the overall experience. Video recorded interviews with individual students and student teams during the Sprint also provided a sense of the overall Sprint experience. Results from this initial research have been introduced by Piironen et al. (2017). After the Sprint, stakeholder interviews were conducted individually with six Sprint organizers and jobs-to-be-done interviews held with six attendees. Results of these mixed methods were analyzed using a four-step analysis and design process (Figure 1) intended to evaluate the delivery of the previous implementation and understand the experiences of both the student and teacher. In the first step of the process (Learn & Evolve), content analysis of the open-ended survey questions was used. In the second step (Discover), unique case orientation and insight synthesis were used. In the third step (Define) conclusions were drawn from the analysis using jobs statements, part of the jobs-to-be-done (JTBD) theory and the student-driven ILOs were developed. The fourth step (Develop) used what was learned to redesign the Sprint for the 2017 implementation. Results have been published by Padley (2017) and Padley & Piironen (2017).

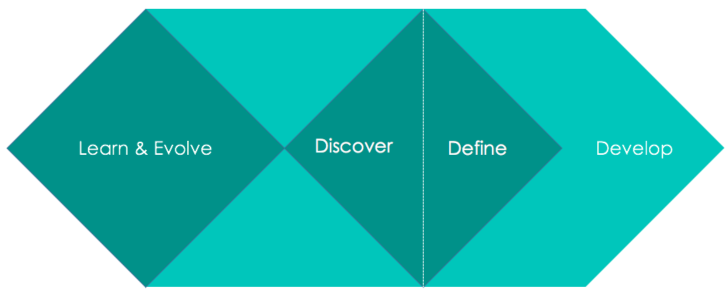

Figure 1. Four-step design process

During the enrollment period for the 2017 Sprint, organizers continued collecting demographic data and details about participant's motivations. This information was primarily used to support team formation. An electronic survey distributed at the end of the Sprint collected both quantitative and qualitative data about the overall experience. A text analysis of open-ended responses provided further insights about the progress made in the second implementation of the Sprint. In both 2016 and 2017, Sprint designers participated in as organizers and facilitators, thereby actively influencing the learning experience while observing and reflecting on results.

APPROACH

In the Finnish higher education system, UAS are focused on preparing students with practical, professional skills for transitioning to working life. This expert job training is designed to respond to the needs of the labor market and provide a pipeline of skilled workers to support regional development. (Arene, 2014; Ministry of Education and Culture, 2006.) It was under this premise the UAS alliance was formed and the Sprint conceived. With the promise of what their partnership would bring, the organizers knew they would need to take a fresh new approach. Embracing a spirit of open innovation, organizers built the Sprint so that it is engaging and adaptable for students by taking a student-centered approach and offering project-based, practical experience to support the school-to-work transition.

Adopting a student-centred approach suggests a fundamental change how education is perceived; there is a shift of focus from how teachers teach to understanding how and what students learn. Education changes from a vehicle driven by the educator to distribute knowledge to an avenue that encourages active student engagement in gaining knowledge through a collaborative approach to learning. This shift is supported by a deeper understanding of the science of learning (Hinton et al., 2012) and is believed to be critical in helping higher education become more adaptable and responsive to both student needs and those of our rapidly changing world (Ojasalo, 2015).

Project-based learning also encourages active student engagement in the process of learning. Edström & Kolmos (2014) argue the introduction of project-based learning was a milestone for student centricity. By nature, the development of a project gives students responsibility for their learning and positions the educator as a guide, there to introduce concepts, methods and ideas to support student progress. Seen as an authentic, practical, and engaging approach, project-based learning also paved the way for the emergence of CDIO and its application specifically in the field of engineering (Edström & Kolmos, 2014).

The commonalities among student-centred, project-based learning and CDIO link closely with the original goals of the Sprint to prepare students with practical, professional skills. Embracing these in the spirit of open innovation requires a new mindset towards collaboration and teaching. For the Sprint, this means that we work to:

- form partnerships built in the spirit of innovation;
- practice what we preach;
- enhance teaching competencies;
- and improve continuously.

Form Partnerships Built in the Spirit of Open Innovation

Contributions from stakeholders such as industry partners, master's-level student mentors, the community and student participants have played an important role in the overall success of the Sprint. In turn, the Sprint serves as a platform to co-create value with each of the stakeholders (Ståhlbröst, 2012). As an open innovation initiative, all partners agree that the resulting ideas and innovations are not owned by any one individual or organization, rather, they are open for further development by all. Exemplifying this openness was a 2016 case project sponsored by Novartis which evolved during the Sprint into an idea that is now a full-fledged startup led by one of the student participants.

The management of partnerships has continued to evolve through implementation experience and research. For example, case projects in 2016 were developed together with ten industry partners. While this offered a variety of case projects ranging from cancer care to coworking, it also meant coordinating many project briefs and careful consideration of the motivations and value exchange. This led to increased planning and coordination time and an inconsistent learning experience among the teams. Responding to the needs of organizers, students and facilitators, the following year the case project was supplied by only one industry partner; this enabled participants to have the same level of access to information and support throughout the Sprint.

Practice What We Preach

The Digital Wellbeing Sprint supports students in developing skills in collaboration, co-creation, human-centred design and open innovation. It is important to not only teach these skills but to model them. Afterall, if students are being asked to approach their projects by understanding the users and customers who will be impacted by the final solution (Ojasalo et al., 2015), shouldn't the design of the Sprint be approached in the same way?

This question inspired research to help organizers better understand how student and teacher perceptions align, or misalign, then iterate the design to better meet the expectations of both stakeholders (Könings et al., 2014). Motivations for participation manifested in different ways for different students; some wanted to gain the skills to get a good job, make a career change, or just figure out what to do in life. They were eager to engage in experiences that integrate past learning and will help propel them into the future (Standard 5). At a high level, they all shared a desire for change; expecting to be different upon completion of their degree than when they began. (Padley, 2017). This commonality of motivation yet diversity of desired outcomes emphasizes the uniqueness of each student and the importance of respecting the needs and diversity of students through student-centred learning (ESG, 2015). Embracing this type of diversity represents a shift in mindset from that which is visible – timetables, lectures, learning space, etc. – to the more invisible reality of the student (Heinonen et al., 2010) that includes their motivations and goals for the future.

The research led to a set of 38 student-driven learning outcomes for the Sprint, for example: to experience a sense of self-validation by interacting with and learning from experienced professionals; to test current skills and understandings; and to rapidly improve skills through practical implementation and iteration. (Padley, 2017). These student-driven learning outcomes were then viewed alongside the desired outcomes of the organizers and educators to consider where key improvements could be made for the Sprint the following year.

Enhance Faculty Teaching Competencies

The shift in roles required for a project-based, student-centred learning experience can be challenging for educators. For some educators, moving away from traditional lecturing can lead to the question, "If I'm not lecturing, what am I doing?" The experience of implementing the Sprint as a collaboration among three UAS, each bringing a variety of educators and mentors, all trained in different styles, emphasized the reality of this type of role uncertainty. Furthermore, the research revealed that misaligned role expectations among the educators and mentors could have large impacts on the student experience and learning outcomes. This led to an effort to update practices around course staffing and enhancement of teaching competencies (Standard 10).

Successful implementation of the Sprint required educating the educators in a facilitative approach to learning. The reasons behind the use of student-centred and project-based learning, along with the mindset, roles and skills their implementation requires, needed to be introduced in a way that was clear and compelling. Organizing a pre-Sprint workshop to ensure all facilitators were on the same page about their role and to share best practices has proved to be useful. In the case of the Sprint, university educators attended a half-day workshop alongside master's students who served as Sprint mentors. The result was a group of facilitators with diverse strengths and facilitative approaches to teaching and learning yet a shared mindset.

The pre-Sprint workshop was designed to model a facilitative approach, encourage the exploration of individual strengths, and reduce the hierarchy that traditionally exists between teachers and students. Mixed groups of educators and master's students worked together in teams where each served as a subject-matter expert in their area of expertise ranging from engineering to service design. Educators with a more traditional approach to teaching were able to explore the role of facilitation in project-based work while learning from others with previous experience. The master's students who wished to expand their knowledge of service innovation learned from the educators and seized the opportunity to test their facilitation skills. Through the activities, both stakeholders gained an understanding of the student-driven learning outcomes and explored how they might be incorporated into the sessions.

Learn and Iterate the Experience

Through the surveys, interviews, and analysis, the organizers were able to continuously improve the learning experience; findings from the 2016 Sprint were used in planning and redesigning the 2017 Sprint. Through regular discussions and handover sessions between organizing teams and the researchers, new insights were readily shared and put into practice. The student-driven learning outcomes were considered one by one, each directly affecting the Sprint 2017 planning phase. For example, due to staffing constraints, the 2017 Sprint was reduced from 10 days to six. The research-based, student-driven learning outcomes helped organizers determine how to prioritize content. One of the key priorities was maintaining the Sprint's close connection with industry as participants valued learning from experienced professionals. Therefore, the organizers ensured a number of sessions that included perspectives from multiple stakeholders within industry.

Another key takeaway from the student-driven learning outcomes was the importance of learning from peers and gaining new perspectives by working with people different from oneself. Research findings also emphasized the importance of students within a team sharing a similar mindset for the teamwork to thrive. Knowing this, the pre-assignment for the 2017 Sprint was redesigned to include questions that could better assist the organizers in the process of team formation with a goal of building multidisciplinary, multicultural teams that could work together most effectively. The redesign also included an article and pre-task which served to further clarify the course content and reduced the dropout rate to zero through better expectation setting.

RESULTS AND DISCUSSION

Plans for the 2018 Sprint are already underway and the organizing team is evaluating how the changes made in the second year impacted the experience of the students as well as other stakeholders. Afterall, a new implementation offers a fresh opportunity to learn and iterate. The continued effort to research and develop the concept based on student feedback is a testament to the continued student-centred design approach.

Student participants from 2017 have shared that the Sprint supported them in learning about best practice and allowed them to gain hands-on experience, resulting in the ability to implement what was learned straight as well as offering new potential for nurturing future innovations. With the clear, step-by-step guidelines giving structure to the process, the fast-paced Sprint was seen as a good way to quickly learn the innovation process in a way that could be applied to future projects. This student feedback is an example of how organizers have seen alignment of the learning delivery with the student-driven learning outcomes. In this case, 'learning through practical implementation and iteration' is also a sentiment reflected in CDIO standard five regarding the iteration of design-implement experiences to reinforce learning.

Close collaboration with the organization sponsoring the case project continues to be vital to the success of the Sprint. As there was only one case project for 2017 with a forward-looking municipality called Lapinjärvi in Southern Finland, students were able to complete a portion of the Sprint on-site. This took the Sprint experience to another level, allowing the participants to dive deeper into the life of the end-customer. One of the students said, “I think going to Lapinjärvi was a great help to gain insight and perspective about the challenge on hand. I think based on the actual outcome during the Pitch, all the teams were more User-centered and had actually addressed the problems as were uncovered during the site visit to the elderly homes.”

The partnerships have also opened doors for further collaboration among stakeholders; two student participants have continued the collaboration with the municipality to further develop one of the concepts born during the Sprint while another student is completing their master’s thesis on a related topic. However, new challenges arose such as how to maintain a steady flow of information among students, facilitators and the case organization’s team while working on-site. Managing these challenges will be an important element of the next implementation.

Overall, the experience related to the learning outcomes was seen as positive by all respondents to the final student survey and a clear majority (all but one) believe their participation in the Sprint will help them in their further studies and/or career. They also felt they had gained more new skills for their professional development during the Sprint compared to regular university/professional development courses.

Another aspect of a successful Sprint was the realization of multicultural and multidisciplinary teamwork as a key learning outcome. Participants from both implementations mentioned teamwork and meeting like-minded people as one of the highlights of their Sprint experience. To approach teamwork and the student experience more holistically, in 2017 organizers hosted voluntary free-time activities. This fostered a sense of team spirit and helped participants make new connections with peers from other teams. It was also a unique opportunity for those living outside of Southern Finland to become more familiar with the host city’s nature and culture. As a result, feedback showed the free-time activities were a significant part of the Sprint, reinforcing the importance of taking a holistic view of the student experience.

The effort to enhance the teaching competencies of the facilitators will continue to be a focus for the Sprint. Striking a balance between giving teams space and sharing knowledge to steer the team’s work is not an easy task. The importance of getting this balance right was highlighted in participant feedback and observed throughout the Sprint. One student simplified the role saying, “the mentors were very helpful and needed in order to understand the processes and innovate.” It is not realistic to expect teaching styles to change overnight; however, anecdotal feedback from facilitators who were initially skeptical about the need for the pre-session workshop and a facilitative approach has been positive.

As mentioned earlier, maintaining clear communication with the case organization when working on-site presented challenges, this was especially true for facilitators who were themselves new to the organization. Looking forward, the pre-session workshop could be hosted on-site with an invitation extended to the partner organization. This arrangement could help facilitators become more familiar with the case and build connections with the case partner. While existing research focuses on the value co-created with students through the Sprint, further research to understand the value co-created with the case organization would offer a new and valuable perspective on the role of open innovation.

CONCLUSIONS

Laurea, Haaga-Helia, and Metropolia Universities of Applied Sciences have organized the Digital Wellbeing Sprint twice and conducted research to develop the concept further. The Sprint gave students a true Conceive-Design Experience and improved their substance knowhow simultaneously with their personal, interpersonal, project, process, and system building skills.

Based on the experiences from the pilot Sprint 2016, the concept was modified to have only one partner sponsoring the case project which afforded more focus on student-centricity and the emphasis on staff teaching competence. Still, understanding the Sprint process and the shift in roles of the educators and students proved to be challenging, especially for those with little or no experience in non-traditional teaching methods or student-centered project-based learning.

Our recommendations for organizing similar student-centric Conceive-Design Experiences are the following. Form partnerships built in the spirit of innovation and work to identify the value for each partner - particularly the students. If facing staffing limitations, consider concentrating on a single case, high-quality project rather than dividing resources to coordinate many projects. When working with partners, use the same principles around design and teamwork you teach to Conceive-Design the learning experience; in other words, practice what you preach. Consider the shifting roles required for project-based student-centred learning and, where possible, work to enhance teaching competencies because “you can not keep doing the same thing every day and expect different results”. Last but not least, use all you learn to improve your concept continuously.

The continued effort to research and develop the concept in a way that includes student feedback is a testament to the continued commitment to a student-centred design approach. Each new implementation offers an opportunity for improvement, from deepening partnerships with industry while providing high-quality case projects to designing content in a way that considers the student’s learning objectives and the holistic student experience.

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BIOGRAPHICAL INFORMATION

Antti K. Piironen is a Principal Lecturer of Smart Systems Engineering in the School of ICT at Metropolia University of Applied Sciences. He collaborates regularly with universities in Europe on topics related to joint courses, teacher exchange, and curriculum design. His current scholarly activities focus on the providing professional ICT engineering education using mixture of modern and traditional teaching tools and methods.

Ann Padley is a Teaching Fellow in Design Thinking with the Centre for Innovation and Entrepreneurship at the University of Bristol. Her work focuses on the design of project-based learning experiences and the use of co-creation, facilitation and mentoring to help others develop skills in design thinking and creative problem solving. Her practical, student-centred approach to learning is influenced by her background and ongoing work as a marketing and design thinking consultant.

Kaisla Saastamoinen is a Master's student at Laurea University of Applied Sciences, majoring in Customer-centered Service Development and Service Design. Her Master's thesis explores the possibilities of education and student-centricity in supporting individuals in the era of new work. She served on the 2017 Sprint organizing team with a special interest in the role of Sprint facilitators.

Corresponding author

Dr. Antti K. Piironen
Metropolia University of Applied Sciences
Vanha maantie 6
FI-02650, Finland
+358-40-555-2871
antti.piironen@metropolia.fi

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CO-CREATIVE EDUCATION BEYOND CULTURES AT KANAZAWA INSTITUTE OF TECHNOLOGY

Tomohito Yamamoto, Minoru Nakazawa

Department of Information and Computer Science, Kanazawa Institute of Technology

Masako Osuna

Office of Industry-University Collaboration, Kanazawa Institute of Technology

ABSTRACT

Everyone recognizes the value of young students from all over the world understanding each other beyond cultures in order to solve the problems the world is facing. In addition, universities must exist as a central place to foster such global discussion and creation. However, Japanese universities are gradually losing their global position. In response to this situation, since 2014, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) in Japan has been developing the “Super Global University Creation Support” project to promote the globalization of universities. In order to strongly advance the globalization of education at Kanazawa Institute of Technology (KIT), the president developed the framework “co-creative education beyond cultures” in September 2016. In this co-creative education, we have divided the problem of globalization as “Outbound” and “Inbound” and created various programs to address both. As a representative program of “Outbound,” KIT developed a new dual degree program with Rochester Institute of Technology (RIT) in 2017. In this program, students of both universities can earn degrees from both schools by spending one year at RIT and one year at KIT and exchanging the units earned at each school. As a representative “Inbound” program, KIT developed a joint internship education program for students of Vietnam Japan Institute of Technology (VJIT) and KIT. In this program, VJIT students prepare for the internship in Vietnam, as well as in Japan. After that, they participate in an internship with a Japanese company for several weeks. During this program, both during the education portion at KIT and during the internship, each VJIT student is paired with a student from KIT. KIT intends to strongly promote globalization by enhancing these programs, as well as developing new joint programs with international universities and companies in the future.

KEYWORDS

Global Education, Dual Degree Program, Joint Internship Education Program, Standards: 4, 5, 8, 11, 12

INTRODUCTION

Everyone recognizes the value of young students from all over the world understanding each other beyond cultures in order to solve the problems the world is facing. In addition, universities must exist as a central place to foster such global discussion and creation. However, Japanese universities are gradually losing their global position. According to the university rankings by Times Higher Education in 2017, there are only 2 Japanese universities (Tokyo and Kyoto University) in the top 100 universities in the world. Also, these two universities are no longer the top universities in Asia.

This change in education ranking seems to overlap with changes in the global position of engineering companies in Japan. For example, from the 1960s to the 1980s, Japanese industrial products led the world market (Vogel, E., 1979), but in the 1990s, the presence of Japanese companies gradually became smaller. Since the beginning of the 2000s, Japanese companies have not been competing with global companies, such as Apple, Google, and Amazon. The reason for these changes in the global positions of Japanese engineering companies and Japanese universities appears to be same – lack of innovation based on a global perspective.

In the 1970s and 1980s, Japan had the advantage of a diligent and simple ethnic workforce that provided high quality industrial products at low cost. In addition, engineering education at universities had the advantage of educating diligent employees, who shared the same high level of knowledge and skills, to produce high-quality industrial products. Meanwhile, from the 1990s to the 2010s, the quality of engineering in Asian countries increased, and the price competitiveness of Japanese industrial products decreased somewhat. In addition, companies have been required to create innovative products that not only have high quality and low prices in the global market, but also provide a new user experience that creates undeveloped markets. Apple, Google, Amazon, and Facebook are considered the most successful companies in this respect (Deighton, J. & Kornfeld, L., 2013).

In contrast to the success of such global companies, many Japanese companies have been unable to change corporate governance because of past success (IMD, 2017). Japanese higher education has also not changed its antiquated method of cultivating diligent human resources with a homogeneous set of knowledge and skills. As a result, human resources capable of producing innovative products that can be acquired by global markets have not been developed. This is one reason why Japanese companies and universities have lost their global positions.

In response to this situation, in 2014, the Ministry of Education, Culture, Sports, Science and Technology in Japan (MEXT) began developing the “Super Global University Creation Support" project to promote the globalization of universities. In this initiative, the ministry selected 13 universities as “Top-Level” universities aiming to be within the top 100 in the world university ranking and 24 universities as “Globalization-Driven” universities that will promote the globalization of universities as soon as possible (MEXT, 2014). For each selected university, various programs have been developed. For example, Shibaura Institute of Technology developed multiple Project Based Learning (PBL) courses jointly with overseas affiliated schools and developed engineering education from various perspectives (SIT, 2014).

In order to advance the globalization of education at Kanazawa Institute of Technology (KIT), the president developed “co-creative education beyond culture” in September 2016.

Originally, KIT began educational reform in 1995 and developed the student-centered education program to foster “engineers who think and act on their own” (KIT, 2016). During the reform process, KIT introduced active learning into the whole school and tried to enrich students’ subjective learning.

On the other hand, concerningAs for globalization, KIT’s only effort was the implementation of an exchange program that provided language study. In engineering education, globalization was hardly considered. In order to change this situation, the working group of co-creative education beyond culture divided the problem of globalization into “Outbound” and “Inbound” and have created various programs to address both.

As for Outbound programs, we have been developing joint educational programs with overseas affiliated schools such as a dual degree program and “Learning Express.” Also, we have been developing the “English Language Immersion Camp” where students engage in various activities using English for a short period of time.

As for Inbound programs, we have been enhancing language programs with affiliated universities and developing short-term engineering programs for Asian students. In addition, we have been developing the joint internship program with Vietnam Japan Institute of Technology (VJIT).

By implementing these programs, we will promote KIT’s globalization, which has been delayed thus far. Moreover, we will combine this globalization with our original education style and CDIO standard (4, 5, 8, 11 and 12) to foster students who can realize innovation from a global perspective. In the following two sections, a representative Outbound and Inbound program are described.

OUTBOUND PROGRAMS

utbound programs of co-creative education beyond culture, KIT has been trying to create opportunities for KIT students to travel outside of Japan and to engage in innovative engineering activities through interactions with students from various countries. The programs in development are listed below:

- Dual or joint degree program with Rochester Institute of Technology and other overseas affiliated schools
- “Learning Express” where students of Asian universities visit rural places in Asian countries in order to solve local problems using the design thinking method
- “English Language Immersion Camp” aiming to improve language skills during a short time period
- Introduction of English education in specialized subjects in each department to enhance practical language skills

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IT developed a dual degree program with Rochester Institute of Technology (RIT) in 2017. KIT and RIT had a history of partnerships for over 20 years and both schools share a common strength of student-centered engineering education. After the celebration of the 20-year partnership, both institutes discussed the next 20 years and agreed to develop a new program to foster global students. It took more than two years to develop this program, in order to ensure consistency of the programs and to coordinate the semester schedule. The memorandum of agreement between the two institutes was finally concluded in June 2017.

The outline of this program is as follows. Students in the master's program at KIT and RIT spend one year at each institute and acquire credits by taking the necessary courses. In addition, each student is supervised by a faculty member from KIT and RIT and completes a master's research project. Units acquired at both universities are transferred respectively, and it is possible to acquire a master's degree from both KIT and RIT if the student satisfies the graduation requirements. Figure 1 shows the list of unit acquisition.

<For KIT Students: 18 credits taken at KIT and 15 credits taken at RIT>

For RIT Degree (30 credits)	**For KIT Degree (30 credits)**
Courses taken at RIT = 15 credits • Analytical Topics (3 credits) • Flexible Cores (6 credits) • Graduate Elective (3 credits) • Thesis (3 credits)	Courses taken at KIT = 18 credits • Thesis (6 credits dual enrolled) • Technical Subjects (6 credits) • Global Innovation (4 credits) • International Internship/Business – (1 credit) • Professional Ethics in Engineering – (1 credit)
Transferred courses = 6 credits (from KIT) • Global Innovation (4 credits) • International Internship/Business – (1 credit) • Professional Ethics in Engineering – (1 credit)	Transferred courses = 6 credits (from RIT) • Analytical Topics (3 credits) • Flexible Cores (3 credits) –
Dual-enrolled credits = 9 credits (from KIT) • Thesis (6 credits) • Technical Subjects (3 credits)	Dual-enrolled credits = 6 credits (from RIT) • Thesis (3 credits) • Flexible Core or Graduate Elective (3 credits)
Additional courses taken at KIT or RIT =6 credits	Additional courses taken at KIT or RIT =3 credits

Figure 1. Classes and credits should be acquired at RIT and KIT

The total number of units that must be acquired at both universities is 30, and 15 to 18 units are acquired at the student's home institute. Of these subjects, some course were newly developed for this program from the CDIO standard 5 and 8 point of view. One such course is "Global Innovation," which is offered at KIT. In this course, PBL will be implemented in a short-term Hackathon style, utilizing the new campus of International College of Technology (ICT) in Hakusan City. Students of KIT and RIT, as well as companies, local residents, and governments participate in this course. These participants propose a solution to global and local problems from diverse perspectives. "KIT Hackathon," which is the prototype of this course, has already been conducted several times (Figure 2). In this activity, various participants have proposed diverse solutions, but more advanced and deeper solutions will be produced by adding global perspectives.

Figure 2. Pictures in KIT Hackathon

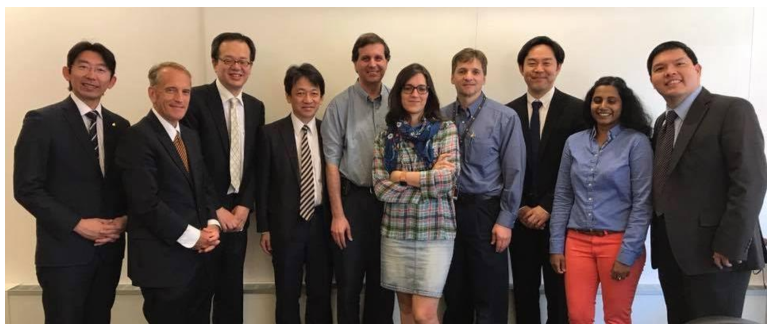

Figure 3. Team members of dual degree program at RIT and KIT

Also, in this program, professors at both institutes (Figure 3) supervise each student's research project. In this project, students will solve global problems from an engineering perspective. RIT has strengths in fields such as computer hardware, security, and machine learning. KIT has strengths in fields such as IoT, human computer interaction, big data, and virtual reality. By fusing these fields, we can foster students with global and diverse research perspectives.

Through this program with RIT, KIT will globalize the institute's teaching system, facilities, and human resources. After that, KIT is considering expanding international partnerships with more universities.

INBOUND PROGRAMS

For Inbound programs of co-creative education beyond culture, we have been developing various programs in order to make KIT a global learning place. In the programs, students from around the world can learn about engineering in Japan and experience internships with Japanese companies. The programs in development are listed below:

- Japanese language training program that includes various engineering activities
- Short-term engineering program for Asian students
- Joint internship program with Japanese companies between VJIT and KIT

In these programs, VJIT and KIT have jointly operated the internship education program since 2016. VJIT opened in 2015 with the aim of fostering students who will become a bridge between Vietnam and Japan. At the opening the school, KIT's project design education was exported, and KIT has been supporting its implementation thus far (Figure 4).

Figure 4. Curriculum of VJIT and pictures in the class

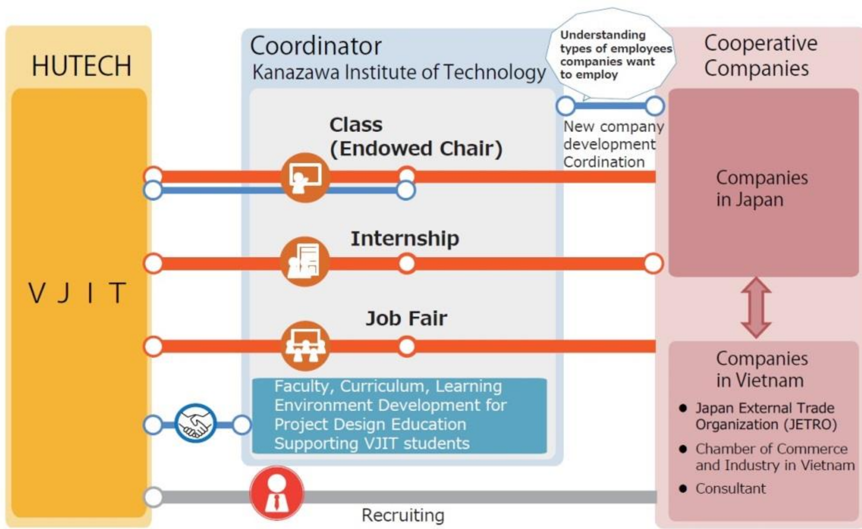

Figure 5. Framework of cooperative education between VJIT and KIT

Students who entered in 2015 became third years in 2017, and these students hope to get a job in Japan or with a Japanese company in Vietnam. In order to assist students with obtaining future employment, KIT has been supporting VJIT students as a coordinator since 2016 with support from AMEICC (AEM-METI Economic and Industrial Cooperation Committee in Japan). Figure 5 shows the framework.

In the framework, VJIT provides a PBL class where students propose a solution for the company where they will be employed, and that considers the CDIO standard 4, 5, 8. Students who participate in such a class then come to Japan and intern with the Japanese companies. Finally, KIT provides a job fair to match VJIT students with Japanese companies. Figure 6 shows the process of the internship, which is the main activity in this framework.

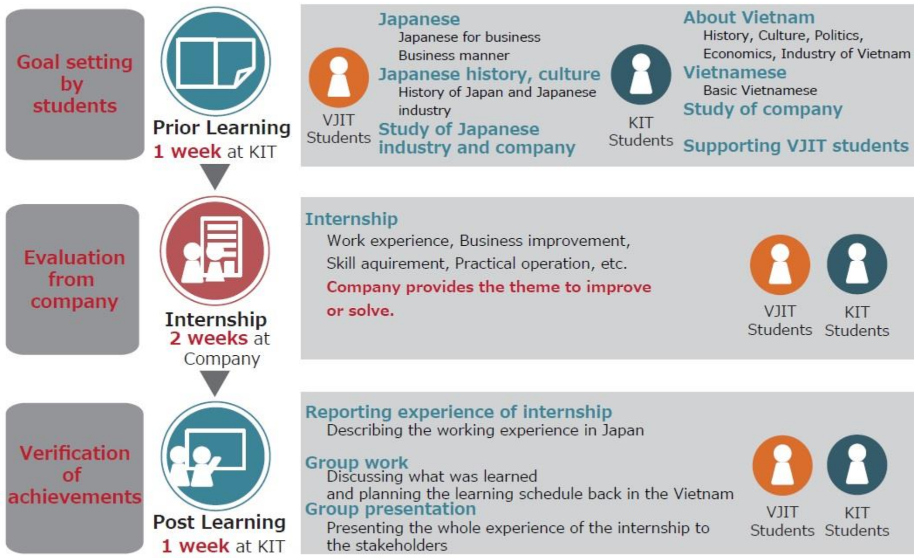

Figure 6. The internship process for VJIT and KIT students

Figure 7. Prior learning for VJIT and KIT students

In this program, VJIT and KIT students are paired together for an internship with a Japanese company. Through this approach, Japanese companies can reduce communication costs associated with hiring Vietnamese students. In addition, KIT students can enhance their communication skills with foreign students. Of course, VJIT students receive a lot of support from KIT students. In this program, for the first week before going to a company, VJIT students conduct a Japanese language training, as well as a preliminary course on Japanese history and industry. At the same time, KIT students learn Vietnamese language, history, and culture and also support VJIT pre-learning. Figure 7 shows the pictures of the first week, and these activities provide introduction to engineering (CDIO standard 4).

After this pre-learning, VJIT and KIT students intern at the company for a one or two-week real work experience (CDIO standard 5). During the first program in the summer of 2017, six VJIT and six KIT students interned with companies. The themes for the internships were “creating an academic version of a software product developed by a company and proposing it to the university,” “picking work and its improvement,” and “practice and evaluation of metal processing.” After work and on the weekend, KIT students shared their social lives with VJIT students, and VJIT students were, thus, less anxious while in Japan.

Figure 8. Pictures of internships at several companies

Figure 8 shows the pictures of internships at several companies. All VJIT students were enthusiastically engaged in the work, and companies highly evaluated the students' attitude toward the work. Although the internship period was short, some students have improved significantly in Japanese, and most of the students' desire to find employment with Japanese companies increased to some degree.

In this program, after completing the work experience, post-learning was conducted from the CDIO standard 11 point of view. During post-learning, students reviewed their employment experiences through group work. During pre-learning, each student evaluated his/her ability about employment based on a rubric (5-stage evaluation) as shown in Figure 9.

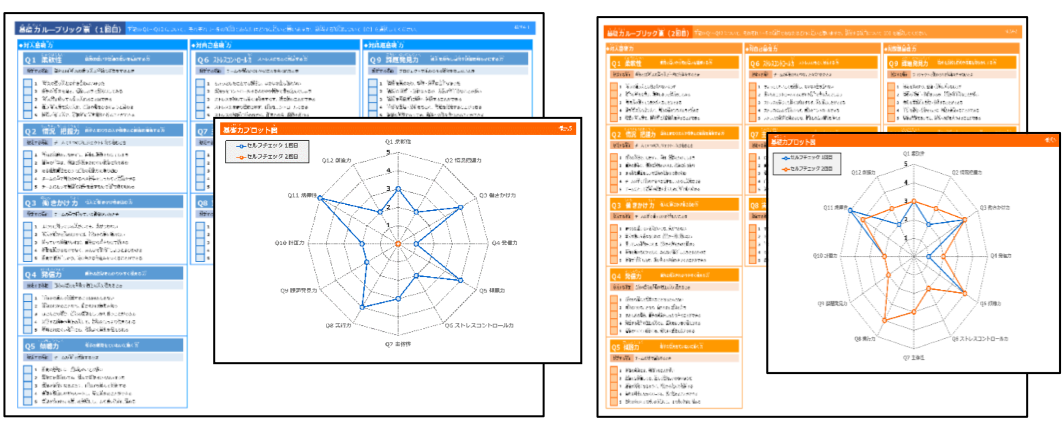

Figure 9. Rubric of business abilities for VJIT and KIT internship

Figure 9 shows an actual rubric, which consists of items such as "ability to step forward," "ability to think thoroughly," and "ability to work in teams." Both VJIT and KIT students evaluated their own abilities for each item at pre-learning, and after that, they decided how much they sought to improve these abilities during the work experience. After the work experience, the companies evaluated the students' abilities using the same rubric.

During post-learning, students evaluated their abilities again after the work experience. Figure 10 shows the averages of all of the evaluation values of the rubrics before and after the work experience. A significant difference was observed (*p> 0.01*) as a result of the Wilcoxon rank sum test on these average values. Based on these results, students from both universities recognized that their ability has grown through the internship. In the individual questionnaire, students provided several positive comments, such as "I understood the way of working in Japan" or "I learned the importance of team work." Also, students provided many comments about further study, such as “I really want to improve my Japanese” or “I want to acquire more specialized knowledge.”

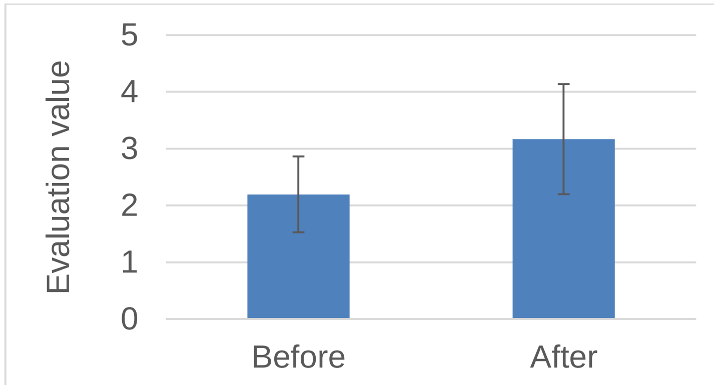

Figure 10. The result of self-evaluation from the rubric

At the end of this program, each student made a presentation about their achievements in Japanese. Figure 11 shows a picture of the final presentations. All staff was surprised at the improvement of Japanese in every VJIT student exhibited during the presentations. At the same time, it was quite impressive that the KIT students reported that the internship program was very fulfilling.

Figure 11. Picture of final presentation of the program

However, it was also revealed that the workload of supporting staff was very high. Students of VJIT had received Japanese language and basic engineering education in Vietnam, but there were individual differences between student knowledge. In carrying out various activities of the program, sometimes the staff had to cover material that was not part of the planned program. In order to solve this problem from the CDIO standard 12 point of view, it is necessary to review both educational programs.

Overall, this program between VJIT and KIT matches the needs of both schools, as well as the needs of Japan, which is currently short of labor, and is being considered for further development in the future. KIT hoped to extend the program to other universities in Asia.

CONCLUSION AND FUTURE WORK

In this paper, the contents of KIT's current co-creative education beyond culture" were described. Specifically, as an Outbound program, a dual degree program with RIT was explained. In addition, as an Inbound program, the joint internship program with VJIT was explained.

KIT will promote globalization by improving these Outbound and Inbound programs in the future. To achieve this, KIT will cooperate with more foreign universities and enhance its relationship with Japanese engineering companies. Moreover, it is necessary to develop the ability of KIT's involved staff to ensure rapid globalization.

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BIOGRAPHICAL INFORMATION

Tomohito Yamamoto is a Professor in the Department of Information and Computer Science in the College of Engineering at Kanazawa Institute of Technology. Yamamoto graduated from Tokyo Institute of Technology (Ph.D. in Computational Intelligence and Systems Science in 2004). He has 14 years' experience of engineering education at the department. His research field is virtual reality, human computer interaction, and communication science.

Minoru Nakazawa is a Professor in the Department of Information and Computer Science in the College of Engineering at Kanazawa Institute of Technology. Nakazawa graduated from KIT in 1991, received a Master of Engineer in 1993 and a Ph.D. in 1999 from the same school. He worked at Fujitsu Laboratory from 1993 to 1996 as a network and computer researcher. He has been working at KIT since 1996. His primary research focus is technology innovation and integration, advance science of robotics, and networking.

Masako Osuna is a Professor in Office of Industry-University Collaboration in College of Engineering at Kanazawa Institute of Technology. Osuna graduated from Waseda University, received a Master of Public Management from Waseda Graduate School of Management in 2005. She joined Japan External Trade Organization (JETRO). She has been engaging at KIT since 2014. Her Primary research focus is on international economy, Korean and Asian economy, internationalization strategy.

Corresponding author

Dr. Tomohito Yamamoto
Kanazawa Institute of Technology
7-1 Ohgigaoka Nonoichi Ishikawa
Japan, 921 – 8501
81-76-274-7515
tyama@neptune.kanazawa-it.ac.jp

CHALLENGING ENGINEERING STUDENTS WITH UNCERTAINTY IN A VUCA SITUATION

Haraldur Audunsson, Thordur V. Fridgeirsson and Ingunn Saemundsdottir

School of Science and Engineering, Reykjavik University, Iceland

ABSTRACT

Engineering practice is gradually becoming more affected by the need for agility, and the dynamic nature of today's world has impacted how situations are addressed, projects are managed and decisions are made. Anticipating a rapidly changing world, future engineers must have competence to manage situations which may be volatile, uncertain, complex and ambiguous (VUCA). Engineering education programs may therefore want to consider instilling some VUCA aspects into their training, aiming to prepare graduates to confront unexpected situations in the context of decision-making and leadership as recommended in the CDIO Syllabus 2.0.

The engineering programs at Reykjavik University (RU) have for several years run a two day "Disaster Week" early in the first semester, an event were students are faced with a disaster of some sort. In the fall semester event 2017 it was decided to analyze by a survey carried out at the completion of the event, the VUCA dimensions of the event and the dynamics within the teams. The participants were a group of 230 first-year students, working in 40 teams. This study shows that challenging engineering students with uncertainty in the VUCA-spirit is a good way to both train and instill a positive view towards teamwork among students, and may lead to a more confident and positive attitude when faced with volatile and uncertain tasks later in their studies.

KEYWORDS

VUCA, Decision Theory, Experiential Learning, Teamwork, Disaster Week, CDIO Standards: 2, 4 and 8.

INTRODUCTION

Engineering and management practices are gradually becoming more affected by the need for agility and the dynamic nature of today's world has impacted how situations are addressed, how decisions are made and projects are managed. The abbreviation VUCA refers to situations that are volatile (V), uncertain (U), complex (C) and ambiguous (A). Although it was initially coined to describe the severe conditions of unconventional warfare, the business and industry sectors adapted VUCA to enhance skills to deal with unexpected scenarios and events (Lawrence, 2013).

The real social environment of today´s business is complex and ambiguous. The idea embodied in the acronym VUCA can be used to describe the complicated real-world circumstances in which strategic decisions must be made. Recent research has tackled many aspects of these complicating realities of real-world social perception. The term VUCA describes the dynamic nature of the world today and has caught on in a variety of organizational settings to describe a business environment (Horney et al., 2010; Bennet and Lemoine, 2014).

VUCA in Engineering Education

Future engineers may face challenging tasks on a worldwide scale, and engineering practices are becoming more global due to ease of communication. This imposes new conditions as future engineers may have to make decisions in environments that are VUCA-like. These environments may include unexpected scenarios and events such as financial crisis, surge of immigration, unstable software systems and natural disasters. Business and industry sectors have recognized a growing need to enhance skills that enable them to deal with VUCA situations. Engineering educational programs may therefore want to consider training students in facing unexpected VUCA-type situations in the context of decision-making (e.g. Gaultier Le Bris et al., 2017; Rouvrais et al., 2018), leadership and for facing rapidly changing world (e.g. Kamp, 2016). Among the goals for undergraduate engineering education that are specifically listed in the CDIO Syllabus 2.0 (www.cdio.org) are "analysis with uncertainty, based on incomplete and ambiguous information" (2.1.4) and "initiative and willingness to make decisions in the face of uncertainty" (2.4.1). Universities in the CDIO initiative might therefore consider using VUCA scenarios as a venue for reaching these goals in the teaching of their engineering programs.

VUCA and Disaster Week, First Encounter at Reykjavik University

The engineering programs at Reykjavik University (RU) have since 2011 run a 2-3 day intensive course, Disaster Week, early in the first semester (Saemundsdottir et al., 2012). The main objective is to enhance interpersonal skills, as well as to break up a long semester and open a venue for students to become acquainted with fellow students. The context of the project is an unexpected challenge that has to be dealt with in teams. In the fall semester 2017 the scenario was the eruption of a prominent stratovolcano that is clearly visible from the campus. RU is participating in a European Erasmus+ project, the D'Ahoy project, along with five other higher educational institutions. The formal introduction of the VUCA theme into RU´s Disaster Week is one contribution to the project. Our objective is to use the experience from this event to aid us in learning how to prepare students for dealing with VUCA situations, and how to define learning outcomes that support VUCA skills (Gaultier Le Bris et al., 2017).

In this paper we describe how we involved VUCA aspects in the Disaster Week event, show the results of a survey, and discuss lessons learned.

VUCA AND DISASTER WEEK HAND IN HAND

Objectives and Planning

The learning outcomes (LO) for Disaster Week 2017 were that upon completion of the course the student should:

1) have experienced teamwork and understand the importance of cooperation and diversity in a group.
2) have been introduced to diverse ways in presenting solutions.
3) have experienced a situation where decisions and planning are based on uncertain information.

The third learning outcome reflects the VUCA emphasis which was implemented in this course for the first time in fall semester 2017. In three prior years, an emphasis was placed on creativity, and training students in a formal brainstorming method had been a part of the Disaster Week course (Audunsson et al., 2015; Matthiasdottir et al., 2016). Training in brainstorming has now become a part of another 1st year course, as the emphasis in Disaster Week has shifted towards VUCA.

A total of 231 students participated in the course, 186 in engineering and 45 in sports science. Students were spilt into groups of 6 to 7 students, hence a total of 39 groups. Ten teachers facilitated in the course, each one advising 2 to 6 groups.

Among the objectives in designing the event was to choose a scenario that would awaken the students´ interest, fit well for teamwork, and to some extent reflect a VUCA situation. A glacier-covered stratovolcano is visible from our campus and, due to its prominence and the steady threat of volcanic eruptions in Iceland, we felt that it would be suitable for the project. It was feasible to make up a realistic course of events that included both minor and major disasters and ambiguous news bulletins, i.e. about the flooding of glacial rivers isolating a small town, disrupted transportation, ash and tephraflows escalating to a imminent major tsunami hitting the city of Reykjavik (Figure 1a).

To give the event a realistic impact at its kick-off, a local TV station helped out by producing a dramatic news alert, including an interview with a well-known local geoscientist. The bulletin announced that an eruption had started, described some initial events and then some speculations on potential development. This resulted in a 3-minute video that was shown at the kick-off session on Thursday morning (Figure 1b).

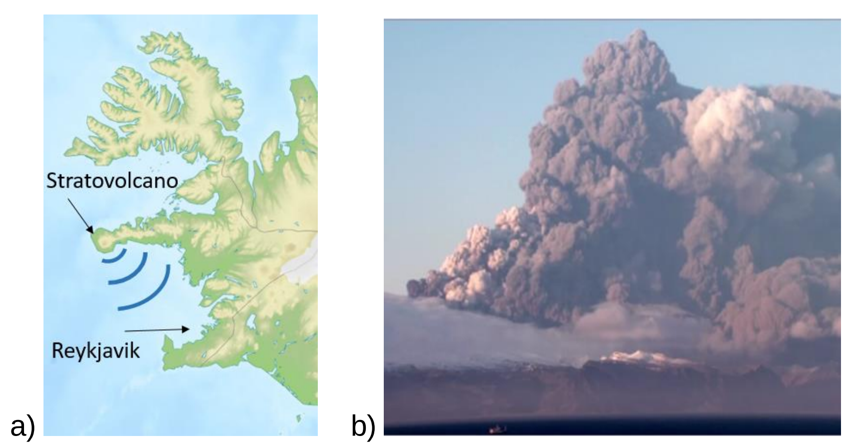

Figure 1. a) Map of Iceland with stratovolcano Snæfellsjökull. b) Clip from the kick-off video (from Eyjafjallajökull in 2010).

The students´ task was to envision themselves as an advisory team commissioned by the government and set up an action plan. All groups started by focusing on evacuation of the immediate threatened region. This entailed finding information on the web and through the local authorities i.e. about the population and size of the area, how to assess flooding and ashfall, the capacity for transporting people by the local fishing fleet, the capacity of the road system and other means of transportation, accommodation for evacuees, health issues and crowd control. And of course decision-making at various stages as the whole event unfolded.

In designing the course, we aimed for a volatile event with dashes of uncertainty, complexity and ambiguity. Our evaluation of the levels of the four VUCA-factors is shown in Table 1.

Table 1. Levels of different factors of VUCA in the Disaster Week 2017 scenario (table adapted from Rouvrais et al., 2018).

Magnitude / variability	Interpersonal	Volatility	Uncertainty	Complexity	Ambiguity
Strong					
Medium	X	X			
Weak			X	X	X

The Event

The Disaster Week started Wednesday afternoon with an hour of short lectures on group- and teamwork, VUCA situations, goals and methods. The unexpected event was introduced early Thursday morning, initiated by a dramatic news bulletin video, and the scenario unfolded throughout the morning (Figure 1) with several fresh news bulletins thrown in to bestow a volatile atmosphere. Students worked in groups most of Thursday (Figure 2a), and at the end of the day there was a short lecture on presentation methods. Friday morning, they worked on summarizing results and designing presentations, which they presented early afternoon Friday (Figure 2b). The chronological sequence of events is outlined in Table 2.

a) b)

Figure 2. a) Students working in groups on Thursday. b) Students presenting their work on Friday.

Table 2. Unfolding of events in Disaster Week, September 13th – 15th 2017.

Wednesday	
3 – 4 PM	**Four short lectures** (15 minutes each): • Working in a group, • Teamwork and VUCA, • Back-of-the-envelope calculations, and • Finding information on the web
Thursday	
8:30 AM	All students together in a lecture hall: **Outline of the course** for the next two days and on deliverables on Friday.
8:40 AM	**Event presented by a** breaking-news bulletin, **a 3-minute video**: An eruption started early in the morning in a glaciated stratovolcano, flooding in a nearby village, Olafsvik, and it appears isolated. The news focuses on an interview with a geoscientist trying to predict the potential course of events, including glacial flooding, ash and potential tsunami.
9 AM – 3 PM	**Students work in groups.** Students go to their working spaces, 2 to 8 groups in each room. Students start working on their action plan. **News bulletins (**spread over two hours): • Eruption just started in a stratovolcano, clearly visible from Reykjavik. • Glaciated volcano, hence local flooding due to melting, nearby village isolated. • Spectacular eruption as seen from Reykjavik, major confusion among the population. • Urgent request from the government for action plans to be delivered at the end of the day. • Major ash plume is seen rising, and heads for Reykjavik due to the wind. • Pyroclastic flow may rush down the slopes of the volcano and into the sea and hence a potential tsunami is evident, initiating a wave few meters high that might hit Reykjavik.
3:30 – 4 PM	**Two short lectures** (15 min each) on oral presentations, flyers and posters.
Friday	
8:30 AM – 1 PM	**Group work** continues and students prepare presentations.
1 PM	**Flyers**. Each group delivers a flyer (A4-format) on their work.
1 PM	**Seminars**. All groups present the results of their work. 8-minute presentations, about 6 groups in each of 6 rooms. Best presentation in each room selected by attendees.
2 PM	**Survey**. On the VUCA aspects of the course and on group dynamics and teamwork. **Feedback.** Teachers give short written feedback to each group.

SURVEY

An internet survey was carried out at the completion of the event, Friday afternoon, about challenges imposed by the situation facing the student teams, i.e. the group dynamics and the VUCA aspects. A total of 219 students were registered for the course, and 191 of them participated in the survey (87%), 89 females (47%) and 102 males (53%).

Regarding group dynamics, the students were supposed to select one (out of three) statement that best described their group. The majority of students (94%, 176 out of the 188 valid replies) responded that their group had worked as a team to find solutions without any one person taking the lead. Moreover, there is no significant difference in opinion between females and males, 96% and 92%, respectively. Results are shown in Table 3.

Table 3. Results on group dynamics.

	Females	Males	Total
The group worked as a unity (team) to find a solution without any one person taking the lead.	85 (96%)	91 (92%)	176 (94%)
One person decided on his own to lead the work and steered the group in finding a solution.	3	7	10
The group was disorganized and without leadership.	1	1	2
Total	89	99	188

Regarding the VUCA situation, four more statements were presented, each intended to reflect one particular VUCA factor i.e. in compliance with Lawrence (2013). Each student responded by ranking each statement on a Likert scale. The ranking showed how well each statement described the student´s encounter with the VUCA situation. The statements were:

(V) Even though it was uncertain what could happen, and there were many possible solutions to all issues, the collaboration within the team was focused and all team members knew what their goal was.

(U) In spite of many things being unclear and uncertain all team members kept calm, where active listeners and accepted fresh ideas when conditions changed.

(C) Even though the situation was complex, with uncertainty and confusing information, we were able to keep all issues under control.

(A) In spite of a steady stream of unexpected, unclear, ambiguous and confusing information, and it was difficult to predict what would happen next, the team remained effective and solution driven.

As there is no significant difference in responses between females and males, we combined the results as shown in Table 4.

Table 4. Students´ responses to statements on how VUCA factors affected their group.

	Statements in compliance to:			
Number of responses / factor	Volatile	Uncertain	Complex	Ambiguous
Definitely agree	101	115	105	109
Agree	65	51	63	56
Disagree	4	3	3	4
Definitely disagree	15	16	14	16
Total	185	185	185	185

According to this survey the majority (90%) of the students felt that their group worked well and efficiently despite the four potentially inflicting VUCA factors, and about 8% definitely disagreed. Because the responses are so alike for the different VUCA factors, it may be argued that the students did not fully distinguish between these factors in this short event.

Considering that the VUCA survey was carried out at the completion of the event, Friday afternoon, we were concerned that the timing might have influenced the responses. We therefore conducted three in-depth interviews a few weeks later with 6 randomly selected students, 3 females and 3 males, talking to two students together in each interview. The students´ comments in the interviews included:

- uncomfortable initially as the scenario was changing fast
- a little overwhelming because it was their first project at university level
- being expected to estimate instead of detailed calculations was uncomfortable
- confusing how fast things happened initially, but it was interesting
- the project was exciting
- initially we did not know what was expected of us
- appreciated dealing with the project in a group
- the groups worked fine, some mild conflicts initially but they were able to resolve it
- now we know who to work with, and whom to avoid, in future group work
- got to know their classmates better
- there was no conflict in the group - one took the lead in the group, but all participated in taking decisions, so it worked well
- everyone was active in the group, although one was more active than others
- two in the group took the lead and the others in the group were content with it.

The interviews confirmed the results of the survey regarding the group dynamics (Table 3). Also, although one member in a group may have taken the role of a leader, the groups were generally very comfortable with it and no apparent conflict emerged. The interviews showed that, of the four VUCA factors, the volatility was predominating.

RESULTS AND DISCUSSION

Based on the survey and interviews we can conclude that the event provided a very positive experience regarding teamwork. There is no significant difference in opinion between females and males regarding the group dynamics. It is not obvious from the results of the survey conducted at the end of the course that the Disaster Week event is suited to induce strong emotional responses among students regarding the challenges of teamwork under conditions of uncertainty and rapidly changing conditions.

The students were introduced to uncertain information and a volatile situation but in the end they had enough time to make realistic plans, and the consequences of bad decisions were mild as the grading for the course was Passed/Failed. All groups were able to finalize presentable action plans, and most students might therefore have been in a very happy mood when they answered the survey on Friday afternoon. The results of a survey conducted a few hours after they started working on their tasks, i.e. at noon on Thursday, might possibly have been very different. To obtain a more comprehensive view on students´ reactions to working in a volatile, uncertain, complex and ambiguous environment, it would probably be more informative to monitor and assess VUCA factors at various stages of a project, not only at the end. Students did not seem to have differentiated between the four VUCA factors. Most students seem to have given the same ranking to all four statements, without giving the differentiating nuances much thought. It might therefore be appropriate to rephrase the four statements, and/or to make them more related to specific events of the scenario.

Introducing VUCA, although in a mild manner as in this case, so early in a study program encourages personal interaction within study groups. It may also encourage a more positive attitude when students are faced with uncertain and ambiguous projects later in their studies, paving the way for facing more involved and realistic VUCA situations. Both of these are valuable traits, which are not always easy to cultivate in a study program. The VUCA flavor of the Disaster Week appears to be an effective theme to let students experience teamwork and value the importance of cooperation. The three learning outcomes initially stated were fulfilled.

This study shows that challenging engineering students with uncertainty in the VUCA-spirit, in a short course like Disaster Week is a good way to both train and instill a positive view towards teamwork among students, and may lead to a more confident and positive attitude when faced with volatile and uncertain problems later in their studies.

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BIOGRAPHICAL INFORMATION

Haraldur Audunsson, is an Associate Professor in the School of Science and Engineering at Reykjavik University. His interests include physics education and experiential learning.

Thordur Vikingur Fridgeirsson is an Assistant Professor in the School of Science and Engineering at Reykjavik University. He is the group leader at the Center of Risk and Decision Analysis (CORDA). His interests include planning for the unexpected.

Ingunn Sæmundsdottir is an Associate Professor and Director of Undergraduate Education in the School of Science and Engineering at Reykjavik University. Her current scholarly interests focus on curriculum development in engineering and evaluation of teaching and assessment methods.

Corresponding author

Dr. Haraldur Audunsson
School of Science and Engineering
Menntavegur 1
101 Reykjavik, Iceland
haraldura@ru.is

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BLENDED AND PROJECT-BASED LEARNING: THE GOOD, THE BAD, AND THE UGLY

Alexandra Meikleham, Ron Hugo, Robert Brennan

Department of Mechanical and Manufacturing Engineering, University of Calgary

ABSTRACT

Since its inception, the CDIO initiative has advocated the use of experiential learning. Problem- and Project-based learning (PBL and PjBL) have been widely acknowledged as an approach to dovetail experiential approaches into the learning process. The often-cited benefit of this approach is that participation in experiential projects in which students take on roles that simulate professional engineering practice results in dual-impact learning experiences. These experiences encourage the development of both technical knowledge and professional skills – consisting of personal and interpersonal skills, and product, process, and system building skills (Crawley et al., 2014). A drawback to PjBL is that it requires considerable contact time for facilitation, therefore blended learning has been identified as a method to free up limited contact hours for more active engagement. This paper presents our experience implementing blended, project-based learning in a technical fluid mechanics course, including contextual factors which impacted effectiveness of this approach. Student engagement with online lecture material was analyzed using user watch minutes; it was found that techniques implemented to reduce cramming appeared to be effective in achieving this goal. Data from end of term student feedback surveys was used to gain insight into student satisfaction with this blended project-based learning class. Findings from this course were compared with student responses on previous blended and traditional delivery courses. Findings indicated that when perceived workload increased, student perception of quality of instruction decreased. An analysis of expected vs. actual hours revealed that while hours dedicated to course work were lower than expected, students perceived the course load to be much higher than other courses. This suggests that time spent on this course required a higher level of activity and engagement per hour than what students are used to. Instructors should consider whether institutional support exists for the time- and resource-intensive development process of project-based learning, as promotion and tenure reviews could be negatively impacted by student evaluations. The paper will close with a discussion on insights that can be utilized productively by instructors to inform future PBL/PjBL development.

KEYWORDS

Project-based learning, PjBL, PBL, Blended learning, Student-centered learning, CDIO approach, Standards: 2, 3, 5, 7, 8

INTRODUCTION

Project Based Learning

The CDIO approach promotes the use of dual-impact design-build experiences which promote the development of new skills and reinforcement of fundamentals (Crawley et al., 2014a). Project-based approaches ground learning experiences in the real world and transfer responsibility for knowledge development from the instructor to the learner. While project-based learning offers opportunities to demonstrate and develop higher-order learning and professional skills, such as critical thinking, team-work, and leadership, there are many challenges associated with its implementation. While these approaches are beneficial in that they are fundamentally student-centered with respect to knowledge development, this is often not the only criteria that course instructors and designers need to consider when developing project-based approaches. The challenges to widespread dissemination of project-based learning have been discussed by many authors. A study by Norman & Schmidt (1992) revealed that knowledge, even if gained in the context of problem-based learning, may not be easily transferred to new contexts without explicit instruction on the process of transfer. This additional step could represent a barrier to student learning and instructor uptake due to the addition of even further time investment.

Designing and implementing meaningful project-based learning experiences also requires a great deal of creativity and time investment before, during, and after the activity. To support self-regulated learning and formative assessment practice, instructors must spend time facilitating course delivery. To ensure knowledge is transferred to new contexts, additional planning and communication must also be done. Designing and facilitating the experience with the use of formative assessment is usually not sufficient; institutional and systemic constraints often mean that instructors must also summatively assess these activities. Biggs & Tang (2011) offer guidance on constructive alignment for outcomes, activities, and assessment, however under time and resource constraints it can be difficult and unrealistic for instructors to deliver effectively in all areas. Even if instructors are willing to invest additional time into developing effective learning experiences, institutional incentives rarely reward the disproportionate level of time investment required for these approaches (Graham, 2016). Yeo (2005) identified two common barriers to project-based learning: instructors do not easily concede instructional power to students, and students are often too comfortable in their current “reception” role. Without a change in incentive structures for students and instructors it may be an unrealistic expectation that these behaviours change.

Research Questions

To better understand blended, project-based learning approaches, a study was conducted in which these approaches were implemented within a traditionally technical course. Research questions for this particular study were:

- How can student engagement be increased in a blended learning environment?
- What benefits and drawbacks are there to blended and project-based learning that should be considered?
- How do students perceive blended and project-based learning in a technical course which is usually taught in a traditional manner using scripted laboratories?

METHOD

Course Design

In Summer 2017, a fluid mechanics course was offered in a blended format, with approximately 20 hours of lecture videos of technical nature offered online on the video site YouTube.com. These videos were previously described in (Hugo & Meikleham, 2016). In-person lecture time was then utilised to facilitate active learning through use of a personal response system (i.e., clickers) with guided formative assessment, and to conduct design-build activities in preparation for five project-based laboratory experiments. Scheduled laboratory times were used for team-based guided experiments, where students were given objectives and guided formatively through the learning process, and were otherwise required to formulate their own hypotheses and experimental procedure. A brief description of the five experiments, course assessment types and statistical comparison of student performance can be found in a companion paper (Meikleham et al., 2018 [in press]).

Cornell Notes

In previous research on engagement in online learning, we reported on a variety of techniques used to facilitate feedback, formative assessment and self-regulated learning in the context of online courses (Meikleham & Hugo, 2017). In particular, Zhang et al, (2016) reported using Cornell Notes to facilitate student engagement in a blended learning environment. In a 2015 offering of a blended delivery course, one of the authors of this paper found that YouTube video watch minutes peaked the evenings before exams: students appeared to be “cramming” the material. In this course, Cornell Notes were implemented in an attempt to promote earlier engagement, and open up new channels of formative assessment, with the absence of formalized lecture time. Cornell Notes were given a weight of 5% of the final mark and were due three days before each week’s PjBL experiment and corresponding weekly quiz.

Data Collection and Analysis

The experience of offering a blended project-based learning class will be examined through both qualitative and quantitative lenses. YouTube.com offers access to valuable user analytics which help to provide an insight to user engagement with the course content. User watch minutes plotted against key dates in the semester were used to compare engagement across two similar courses from a 2015 and 2017 offering. Ratings on a variety of questions from end of term student evaluations were compared across the two years. A bubble plot relating workload with overall course instruction was used to explore results from two courses offered between 2000-2005 using traditional face-to-face lectures and scripted laboratories, courses taught from 2013-2015 using blended delivery and scripted laboratories, and courses taught from 2015-2017 taught using blended delivery and project-based laboratories. In the 2015 course offering, only three of the five laboratory experiments involved project-based learning with only one of these requiring extra time beyond the scheduled laboratory period. The other two laboratory experiments were scripted involving step-by-step instructions as applied to existing equipment. Qualitative reflections are made based on student observations from the Summer 2017 semester.

There were 53 students enrolled in this summer course, approximately 20% were Civil Engineering students, and 80% were Mechanical engineering students. Distribution of year of study from first to fourth year was 4%, 30%, 60%, and 8% respectively. Gender distribution was approximately 80% male and 20% female.

Student End of Term Surveys

Anonymous end of term student surveys are conducted by the administration to gather data on student satisfaction and experiences in each course. Students are asked to rate the course and instructors on 12 criteria ranging from instruction to evaluation and support, ranking is on a Likert scale from 1-7 ranging from unacceptable to excellent.

Limitations

The design of this course was such that it offered many “active” interventions at one time. On the one hand the classroom was flipped, where students were required to take responsibility for watching YouTube lectures on their own time, on the other hand the student contact time was used in active engagement where the students guided their own discovery with facilitation by the instructors. This may have been a difficult adjustment for many students. It is difficult to ascertain for certain which of the interventions the students had affinities towards, and which were the ones the students rejected. The analysis presented in this paper was motivated by reflections from informal discussions with students and teaching assistants, and formal findings from the end of term student surveys. Many of the analyses in this paper were motivated by questions that arrived from day-to-day interactions with the students. Since the course was not run as a controlled experiment with different interventions tested and controlled, it is impossible to parse out which of the interventions truly led to the results we observed. Where possible we have included anecdotal experience that may help to contextualize the findings, however no causal relationship can be determined.

This course was offered during a condensed summer semester which provided the benefit that students and instructors could be completely immersed in the experience. It is possible, however, that this led to a selection bias with a sample of students that were unrepresentative of the population. Students studying in the summer are more likely to represent two extremes of the population: they are either repeating the course due to previous failed attempts or are keen to accelerate their programs. Students repeating courses with labs are often given credit for the lab component in their subsequent attempts if they have passed the lab previously. In this offering the students were not given credit for past labs as the project-based active learning labs were not considered to be substitutable to previous course offerings. This may have negatively impacted student attitudes causing a bias in their perception of the course.

RESULTS

YouTube Watch Minutes and Cornell Notes

Figure 1 and 2 show a comparison of user watch minutes for the fluid mechanics YouTube videos from 2015 and 2017 during which a comparable version of the course was offered by the same instructor. Red dashed lines indicate quizzes and exams.

Figure 1. 2015 YouTube watch minutes.

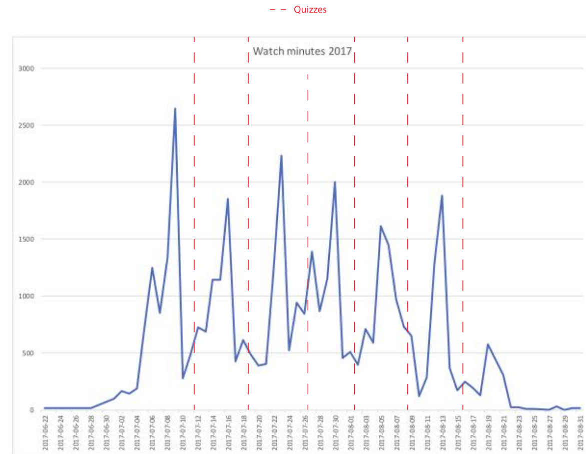
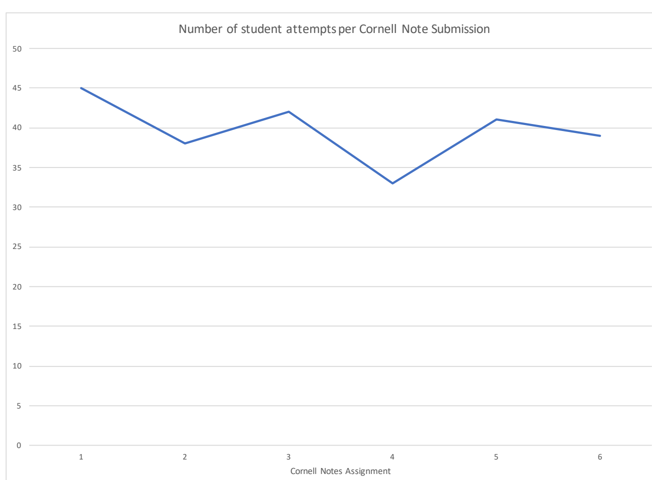


Figure 2. 2017 YouTube watch minutes.

Cornell Notes were not implemented in the 2015 version. It was found that students in the 2015 course watched the course material directly before quizzes, whereas in 2017 this was not the case. Peaks observed in the 2017 graph coincided with the evening that the Cornell Notes were due, as students rushed to get their submissions completed. Cornell Notes were therefore highly effective at influencing student engagement behaviour with the online material, despite the relatively low weight (5%) that it contributed to the final grade. In general, student response towards the Cornell Notes was negative. Several comments were made to the instructors during the semester. Students complained that they did not like having to follow a rigid structure for their note taking and that they spent many more hours on the notes than they felt contributed towards their learning and their final grade. It is interesting to note, however, that the number of students submitting Cornell Notes did not change a great deal over the semester, as noted in the graph in Figure 3.



- Figure 3. Number of student attempts per Cornell Notes per assignment.

Student reception to the Cornell Notes will be further discussed in the End of Term Course Evaluations section.

End of Term Course Evaluations

University-administered end of term surveys (USRIs) measure student response to a variety of questions pertaining to course load, instruction, assessment fairness and respectfulness of the instructor. Figure 4 and Figure 5 show average student response to the USRI questions for both the 2015 and 2017 deliveries. In most categories there was an improvement in student response from 2015 to 2017, indicating that students were more satisfied with the 2017 course offering despite the increased workload (in the form of Cornell Notes and more involved project-based learning laboratories).

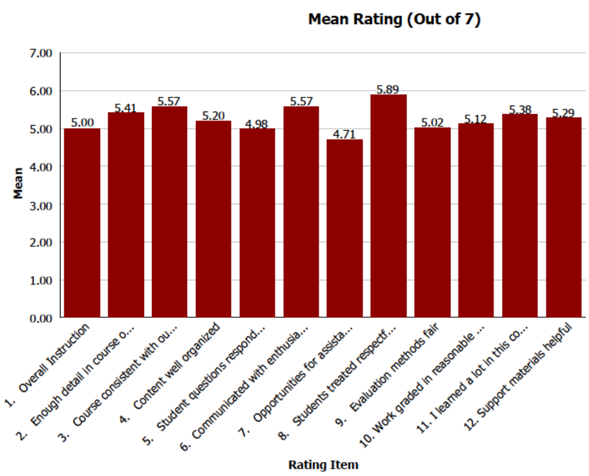


Figure 4. 2015 USRI Results.

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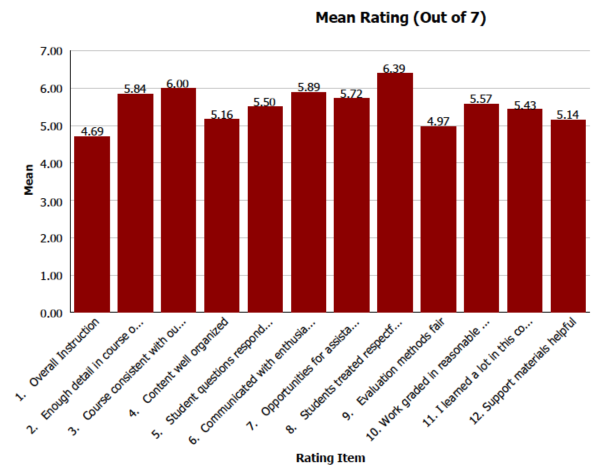

Figure 5. 2017 USRI Results.

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Figure 6 shows a more detailed comparison of the change in USRI Results between 2015 and 2017, with negative values indicating "poorer" performance and positive values "improved" performance. It is noted that the responses to both Question 1 – *Overall Instruction* and Question 12 – *Support materials helpful* decreased from 2015 to 2017. In examining student response to Question 12, it is believed that the open-ended nature of the laboratories, designed to improve student learning, left students feeling less supported. Considering the response to Question 1, the students were less satisfied with the overall learning experiences offered by the 2017 course format, despite improvements being made to almost all USRI categories.

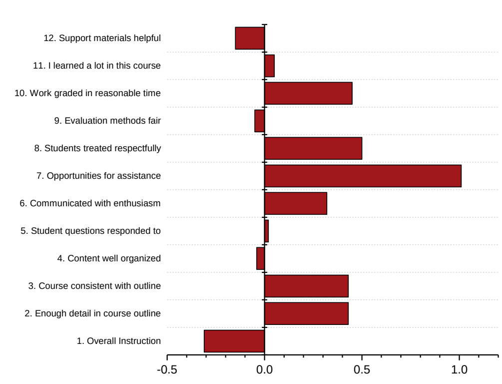

Figure 6. Detailed comparison of change in in USRI results by question.

To further understand why the response to Question 1 – *Overall Instruction* in 2017 decreased while most other USRI categories improved, the demographics for the response to Question 1 were examined. A supplemental question in the USRI survey asked students about course workload, if it was Much Lower, Lower, About the Same, Higher, or Much Higher than other courses. A bubble chart was created comparing student responses to question "1. Overall Instruction" with the demographics question "How does the workload from this course compare to your other courses?" In creating this bubble chart similar results from other courses taught by one of the authors dating back to 2000 were also considered. This included two courses from 2000-2005 using traditional face-to-face lectures and scripted laboratories (Green bubbles), courses taught from 2013-2015 using blended delivery and scripted laboratories (Red bubbles), and courses taught from 2015-2017 using both blended delivery and project-based learning laboratories (Blue and Purple bubbles).

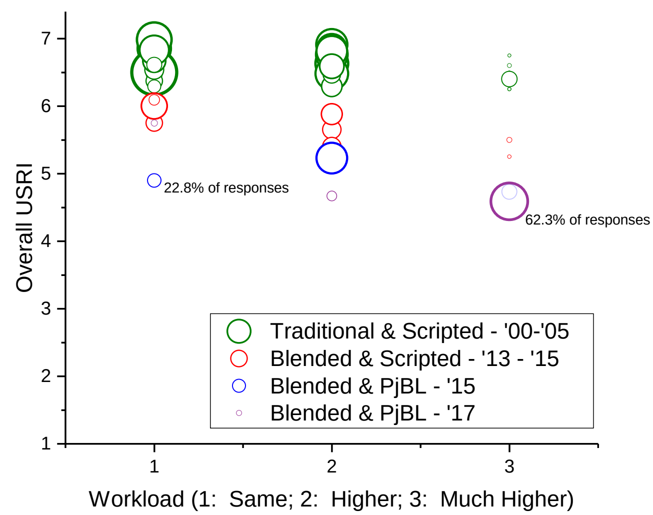

Figure 7. Bubble plot demonstrating relationship between workload, overall instruction and frequency of response (bubble sizes).

The plot demonstrates that the best performance, as indicated by USRI Question 1, is achieved using traditional face-to-face delivery and scripted laboratories (Green bubbles). Blended delivery with scripted laboratories (Red bubbles) results in intermediate performance, with Overall Instruction starting to decrease for students who perceive that the workload has increased, something that was not observed with traditional delivery (Green bubbles). Blended delivery with project-based learning laboratories (Blue and Purple bubbles) results in the poorest performance. Approximately 62.3% of the respondents from the 2017 fluid mechanics course felt that the workload was "much higher" than that in other courses and these students also gave the lowest Overall Instruction rating that the instructor has encountered in nearly 20 years of teaching. Given the large span of time between 2000-2005 and 2013-2017 it is not possible to conclude if this result is due to a change in course design or a change in student habits and attitudes. Nonetheless, a reduction in Question 1 - *Overall Instruction* of this magnitude is not a positive result, especially when trying to encourage professors to adopt project-based learning in their engineering courses for the development of professional skills. This is the fundamental premise upon which CDIO Standard 3, Integrated Curriculum, is based upon. This result may help to explain why a recent survey of CDIO collaborators worldwide found Standard 10 – Enhancement of Faculty

Teaching Competence – the most challenging CDIO Standard to influence (Malmqvist et al., 2015). It is possible that instructors have attempted such interventions in their courses, but when they find an increased workload with decreasing student evaluations, they quickly retreat to traditional delivery.

A second section of the USRI involved free-form student responses to two questions: *If appropriate, please comment about the Laboratory and/or Tutorial section(s) in this course* and *Please provide general comments about the course.*

Students found that labs and lectures both required too much time investment, resulting in the higher than normal course load reported in the USRI demographic questions. A word co-occurrence analysis using VoSViewer found that the most frequently co-occurring word pair in student surveys was lab-time. This supports the claim that students found the labs too time-consuming.

The following are a sample of student responses:

- *"Wish the manual explicitly told us to calculate certain things rather than leave us to "discover" what we need to find."*
- *"We had 5 labs and therefore 5 lab reports. This is too much for a summer course. Basically meant we had to do labs every week."*
- *"Labs were good but some of us felt it was graded too harshly."*
- *"The laboratories were the most enjoyable portion, as it most related to a real-life situation. Conducting the experiment and picking your own methods for testing is very valuable for us in the future."*
- *"The labs are worth 25% of the overall grade but take up 75% of the time and the exams are worth 70% and content covered had to be done on our own time."*

Responses indicate that students in general were not satisfied with the amount of time they were expected to spend on the course, and were particularly unhappy with the assessment weighting and methods used. Rubrics were constructively aligned with learning objectives and activities for the course, however it also appears that some students felt that the marking was unfair on the laboratories. In interaction with students during the semester, some complained about being docked marks by the graders (teaching assistants – TAs) for unclear reasons. It appeared that these experiences may have negatively impacted their attitudes and therefore engagement with the course. Despite clear communication of expectations, there was sometimes a disconnect with the TAs on the importance of open-ended project-based learning. The teaching assistants also expressed that they were not experienced in learning in such an environment and were less comfortable marking in it. It became clear that there was a lack of alignment between the instructors and the previous experiences of the teaching assistants. Despite all of the time invested in developing a constructively-aligned project-based learning course, it appears that student attitudes were influenced by a factor that is not often discussed in course design: teaching assistants. While it may be argued that an effective rubric should overcome these barriers, this was not our experience in this course. The time to design and implement the course was significant for a full-time graduate student and faculty member, and to add the instruction and training of teaching assistants to the course development process would have added an additional demand that was time prohibitive. This is a clear scalability issue, as taking the time to educate and equip all teaching assistants on the benefits of this approach presents yet another barrier. A similar experience has been found with TAs having slow turnaround times on marking, yet during instructor evaluation (promotion, tenure, merit) all TAs are considered equal.

Yet another explanation may be that TAs did not grade any differently than students were used to. The difference may be that students were more attuned to the grades they received on the labs given their increased level of engagement and the time that they had invested in the laboratories. That is, the real change was that the students more closely examined the assessment that they received. With traditional laboratories, students often copy previous reports and thus they may be satisfied if they attain an average grade and are not caught for academic misconduct. Project-based learning has the potential to reduce plagiarism, however it may result in negative student perceptions on assessment.

Time Comparison – Student

According to the university course calendar, this course is expected to consist of up to 39 hours of lecture, 19.5 hours of tutorial and 19.5 hours of laboratories for a total of 78 hours of contact ("Courses of Instruction - How to Use," 2018). Realistically, this is an over-estimate of the hours students spend in contact as holidays, midterms, and unexpected cancellations would reduce this value. Notes were kept on student-team completion times for our design-build experiences, and high and low estimates for actual student time spent on task were calculated. See Table 1 for more information:

Table 1. Breakdown of contact hours for expected, high and low values for this PjBL course

	Traditional (Expected)	**PjBL – high**	**PjBL - low**
Lecture Hours	39	20* (online)	20* (online)
In-person Laboratory Hours	19.5	48	37
Tutorial Hours	19.5		
Total Contact	78	68	57

*While 20 hours may be lower than the traditional value, these hours are compact and spent fully on task; there is no time spent erasing the board or answering questions, for example. In this blended delivery mode, this time was then transferred to the active tutorial and design-build sessions.

It was found that two or three student teams would regularly complete their design-build projects in less than the allocated amount of time. This resulted in the approximation for the low hours students spent in contact at 57 hours (assuming students watched all lecture videos once). There were several teams that consistently took all of the allocated time to complete their builds, and a calculation of their contact was 68 hours, which was ten hours lower than the course calendar contact hours. It is possible that teams that struggled to complete their builds in time were the ones who felt that the workload was heavier than expected.

Students are often expected to spend 1-3 hours on homework per hour of contact time, as estimated by the Carnegie Unit. Following this estimate, students would then be expected to spend 78-234 additional hours per semester on homework for the Summer 2015 fluid mechanics course. Given the shorter summer semester, this equated to 12-36 hours of homework per week. In discussion with several students during the semester, the informal estimate that students said they spent on homework was between 10-15 hours, which was on the lower end of the estimated expectation. Additionally, students admitted to watching the online videos at 2 times the speed, which means that in the extreme case they could have reduced lecture hours from 20 to 10 for the entire course.

There is no evidence that students spent more time than the institutional or standard expectation for similar credit courses. However, it appears that the students' perception is that they spent many more hours on this course than their other courses. This indicates that student engagement and activity per course credit hour increased, meaning that the students were spending more hours of this course actively engaged. In general, it appears that students are used to spending their hours more passively. It is interesting to note that institutional policies often only indicate the number of hours students are expected to be in "contact"; they often say nothing about what the depth and quality of that engagement should be. One assumes that all prescribed contact hours should be spent 100% engaged, but the reality is that this is not the case. One hour watching a concentrated online video or engaged in a project-based learning course is not equivalent to an hour sitting in a traditional lecture. In the future, post-secondary institutional policy improvements could be made to recognize and measure the nuanced differences in engagement levels associated with different methods of delivery.

Time Comparison – Instructor

The design team for this course consisted of a Professor and full-time graduate student. Planning for the Summer 2017 fluid mechanics course began months before the course was offered. Approximately 700 hours (18 hours per formal lecture hour) were spent developing and implementing the five project-based learning experiences for the students. On an institutional scale, instructors typically spend anywhere from 2 to 6 hours per lecture hour developing course notes the first time teaching a course. The development of the project-based learning experiences required, at a minimum, three times the amount of time required to develop a new course. There is a disconnect between institutional support for the number of hours required to develop these experiences and what is budgeted by the institution.

Most research-intensive universities rely to varying levels on the response to USRI Question 1 - *Overall Instruction* (or an equivalent form of question) for faculty Promotion, Tenure, and Merit Increment. As a result, most professors closely monitor their performance on this question and learn to adjust their teaching so as to maximize their score on this question. If an approach to teaching is proven to result in stronger learning outcomes yet requires more time and results in a lower response to USRI Question 1, very few professors would be willing to compromise career success (employment, professional attainment, and salary) for the sake of increased student learning.

Qualitative Instructor Observation

Learning Assessment

Informal discussions with students revealed that the general sentiment was that they did not care too much about the intrinsic value of professional development; what they cared most about was performing well on summative assessments. Grades and summative assessments appeared to provide a form of validation that students enjoyed. While validation can also be achieved formatively, the students didn't appear to place the same level of importance on this, they expressed much deeper satisfaction based on performance on their exams. It is possible that this was because a large portion of their course grade emphasized performance on quizzes and exams, which the authors felt were important to validate technical learning outcomes.

One of the previously noted student responses to end of term surveys indicated that students perceived a misalignment between assessment weight and time spent on task. What is interesting to note is that at least one third of each quiz/exam was based directly on the design-build project that students completed. In reality, quiz/exams were not separate from, but *encompassed* material that the students engaged with on YouTube, were assessed on Cornell Notes, and reinforced by active clicker tutorials. By the time that students reached a quiz they may have been formatively or summatively assessed on the particular topic four times, not including opportunities for them to peer- and self-assess these topics in their own self-guided study. A very different picture of the ratio of time on task to time assessed would be achieved by taking a holistic constructive alignment view: that is to consider that many assessments often tested the same learning outcomes. With this view, concepts covered in the active learning labs actually represented 52% of assessment (30% came from direct assessment for reports on PjBL activities and the active clicker tutorials, and one-third of the 65% of summative quiz/exam assessments). Students appeared to view summative assessments as isolated from the project-based learning experiences, rather than a reinforcement or validation of the learning from them. This may be as a result of what Norman & Schmidt, (1992) have identified as the challenge of transferring concepts and principles to new contexts. According to their review, numerous studies revealed that:

> *"Any change in the surface features of a problem impedes the transfer so the problem solver does not recognize the similarity of the underlying concept and the analogy is not utilized. Without specific hints less than half of the individuals in an experiment recognize the similarity between a new problem situation and one they have just read and recalled"* (Norman & Schmidt, 1992)*.*

This finding indicates that when it comes to PjBL activities, students may benefit from more explicit explanations of concept transfer on problems and exams.

Another challenge is that assessment for an open-ended project can be difficult. Both students and teaching assistants struggled with the notion of assessing projects that didn't have a black or white answer. Rubrics were developed which clearly communicated expectations for the projects, however markers still seemed to struggle with assessing reports on the open-ended labs. The course design itself placed a large emphasis on the technical components through summative assessments on quizzes and the final (representing 65% of the final grade), while the project component represented only about 25% of the final grade. Due to constraints on marker resources, it was not possible to give open-ended exam questions as this would have been difficult to manage across the different teaching assistants and would have exceeded their assigned hours. While open-ended exam questions do offer one potential solution, it is unclear how objectivity and consistency could be maintained.

There was a trade-off observed in the tension of verifying uptake of technical knowledge while also assessing professional skills. In future iterations of the course, a more integrated approach to assessing technical and professional skills is recommended. The immediate challenge with this approach is that a significant amount of time is required to develop and facilitate the teaching and learning activities, and even more hours would be required to develop and mark integrated assessments (training markers how to grade them effectively is yet another challenge).

Other authors have rejected the effectiveness of PjBL learning in disciplinary courses altogether. Kirschner & Clark, (2006) argue that human cognitive structures inhibit disciplinary learning in minimally-guided contexts. The limitation to this argument is that their study focuses specifically on declarative type knowledge, or the "methods and processes or epistemology of the discipline" (Kirschner & Clark, 2006). They do not discuss the role PjBL can play to developing psychomotor or professional skills within the context of disciplinary knowledge, which was really the gap educational reform initiatives were looking to fill in the first place (Crawley et al., 2014). We have shown in our companion paper (Meikleham et al., 2018) that the benefit of PjBL is that it brings the study of technical disciplinary knowledge into an integrated context where students can experience professional skills growth. Nevertheless, the question arises whether disciplinary courses are the best place to offer project-based learning experiences and what the optimum blend for guided learning and discovery learning is in this case.

Another explanation for student fixation on exam performance is the reality that they have developed in a system that heavily emphasizes students' self-worth through grades and ranking. Despite advocating the importance of professional skills development, potential employers still heavily consider student GPA, and therefore performance on graded assessment remains an important factor for students in engineering. Many students also expressed the belief that professional skills could be developed later when they attained a job.

Ambiguity

There was a clear discomfort with ambiguity that most students expressed during the lab portion. Despite an emphasis on peer assessment which was meant to promote internal group regulation, some students became visibly disengaged from the challenge posed by the projects, rather than motivated. In general, they had a hard time letting go of the idea that there might not be only one answer, and constantly looked to the instructors to provide that correct answer. Students appeared to dislike their instructors playing the role of facilitator.

It must be acknowledged that every project-based learning experience is different. A major limitation to the above findings is that these may not be generalizable to all project-based learning. An important factor to note is that we engaged in many educational innovations at once. We flipped the classroom, utilized active learning tutorials, and engaged in project-based learning design-build experiments. It is unclear how much of the results observed in this paper were as a result of the cumulative effects from these activies. We expect that they can be mainly attributed to the project-based learning portion, as this represented the majority of their time on task, but we cannot substantiate this claim.

Another finding that has become apparent is that student and TA attitudes and the learning culture of the institution impacted the success of this project. Students which

Implications

Our finding is that there are major cultural shifts required for project-based learning to succeed in technical courses in our institution. Due to the heavy emphasis that is placed on end of term evaluations, instructor evaluation mechanisms (end of term student surveys) would likely have to change. We also recommend that students be exposed more regularly to such projects before they are challenged to apply them in the context of disciplinary learning. This finding is in alignment with previous research that argues PjBL experiences are most effective when they are offered consistently throughout a curriculum (Thomas, 2000). A risk in an institution that has not entrenched a culture of constructivist education (Black & Wiliam, 2009; Vygotsky, 1978) is that students not familiar with this approach may negatively perceive their facilitators if they do not have an immediate answer for their question. In the complex open-ended problem space, it is likely that novice instructors and teaching assistants will face this challenge, and practitioners should be aware of this as a factor in implementation. Students unfamiliar with constructivist education may develop a negative perception of the instructor that is unable to answer their questions immediately. This means that there is a risk of further entrenching the traditional teaching culture as instructors may receive poor student evaluations at the end of term.

An additional recommendation is that it appears the students likely would have welcomed more frequent “traditional” problem-solving sessions. Perhaps this would have helped the students to master the more involved technical concepts in a manner they were more comfortable with. Self-guided learning, while offering the benefit of supporting the development of lifelong learning skills, was perhaps too much for the students to handle while they were also engaged in discovery project-based learning. It is possible that conducting a multi-pronged intervention put unrealistic expectations on the students.

It is difficult to ascertain which of the interventions presented in this paper: blended, active, or PjBL learning resulted in the effects observed. While there were many challenges, our findings are not necessarily that these approaches are ineffective, but that instructors must take several contextual factors into consideration before implementing innovative approaches in teaching, else we risk the rejection of these very important methods. For better or worse students and other key stakeholders may not be ready to embrace the process, and the long-term acceptance of these approaches may require a more metered approach to implementation. The findings in this paper support the need for a systemic approach to engineering education reform (Crawley et al., 2014; Edström & Kolmos, 2014).

CONCLUSION

A number of questions arose while offering this project-based learning course. Students, instructors, and marking assistants often struggled with the new roles that were expected of them in this regime, reflecting a need for instructor/teaching assistant development programs in non-traditional teaching methods. A closer examination of end of term surveys (USRIs) indicated that students felt that overall instruction quality decreased when their perceived workload increased. Students felt that their workload was much higher in this course; comparing the number of hours students were expected to spend versus their actual hours spent indicated that this was not the reality. This finding was likely because students were more heavily engaged during contact hours, resulting in the feeling that the workload was too heavy. The negative result experienced in the overall teaching rating may be an important consideration for tenure-track faculty members who are interested in implementing project-based or blended approaches. If institutions place a heavy emphasis on USRIs (or equivalents), which are based on student satisfaction and perception and not necessarily on the quality of their educational development, it appears that existing incentive systems could be a major deterrent to implementation of innovative pedagogy. If project-based learning does result in superior uptake of critical professional skills, and can meaningfully support the development of technical skills, the question becomes: how do we get buy in from the students for the increased level of engagement that is expected of them? How can we also reduce the barriers, such as time and resources, to develop and assess these learning experiences? We expect that findings from this experience would have been different if students had been more exposed to a culture of project-based or blended learning more frequently in their programs. Additionally, we advocate that student end of term surveys must be revised to reflect more meaningful evaluation criteria and an understanding of constructivist teaching methods if innovative pedagogy is to be encouraged. Pleiss et al.,

(2012) reported that student resistance to change or gaps in understanding can affect attitudes and success of such projects. Such was our experience in this course.

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BIOGRAPHICAL INFORMATION

Alexandra Meikleham is an MSc student in Mechanical engineering at the University of Calgary in Calgary, Canada. Her current research focuses on human-centered design and on engineering curriculum development.

Ron Hugo is Professor of Mechanical and Manufacturing Engineering and the Chair in Engineering Education Innovation in the Schulich School of Engineering. His research interests are in the areas of experimental fluid dynamics, energy systems, and engineering education.

Robert Brennan is a Professor of Mechanical and Manufacturing Engineering and Head of Department (Mechanical & Manufacturing Engineering) at the Schulich School of Engineering. He has served on the Canadian Design Engineering Network (CDEN) steering committee, chaired the organizing committee for the second CDEN conference, chaired the Schulich School of Engineering's first Engineering Education Summit, served as an organizing committee member for the CIRP International Design Seminar, and is the current American Society for Engineering Education (ASEE) campus representative for the University of Calgary.

Corresponding author

Alexandra Meikleham
University of Calgary
2500 University Dr. NW
Calgary, Alberta T2N1N4
1-514-567-8488
alexandra.meikleh1@ucalgary.ca

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THE IMPROVEMENT OF FACULTY COMPETENCE AND COLLABORATION BETWEEN ACADEMIA AND INDUSTRY: A CASE STUDY IN THE ENGINEERING COURSES OF A BRAZILIAN UNIVERSITY CENTER

Sergio Ricardo Mazini, Wesley Pontes, Pedro Sergio Hortolani Rodrigues, Lucas Mendes Scarpin

Departament of Industrial Engineering, Eletrical Engineering, Civil Engineering, Mechanical Engineering
University Center Toledo Araçatuba

ABSTRACT

The search for the training of professionals increasingly integrated into the industrial environment is a constant challenge for higher education and requires the involvement of several actors in this process. The speed of the technological changes and the need for the differentiated profile of the new professionals motivate more and more the search for new partnerships that allow the full development of the students. In this context, the integration among various actors such as industries, class entities, government and academia can help in the development of faculty competence and collaborate in the development of future professionals.

The objective of this work is to report the experience in the development of partnerships between the engineering courses of a University Center in Brazil and several industries, class entities and government that contribute to the development and improvement of the faculty and the resolution of real cases by students through Problem Based Learning. The main motivation for the choice of Problem Based Learning was the application of a methodology that could develop in the students the critical sense, analytical capacity in problem solving and teamwork.

The case study presents an overview of the framework developed for the development of partnerships and the application of Problem Based Learing through real cases from the industry. Throughout the case study the integration of some CDIO Standards is also presented.

The development of partnerships that allow the application of real situations makes the interest and engagement of students increase, enabling the full development of students. The alignment of the curricular guidelines of the courses with the expectations and real situations of the labor market is of paramount importance and the educational institution must provide mechanisms that contribute to the creation of strategies and actions in this sense.

KEYWORDS

problem-based learning, skills development, collaboration, engineering teaching, CDIO Standards: 5, 7, 8, 9, 10

INTRODUCTION

One of the major challenges of higher education is the development of full and prepared professionals for the job market. The practical activities carried out throughout the course should reflect the reality that the students will encounter when joining the companies, thus meeting the expectations of the labor market.

In this context, the realization of partnerships with companies, class entities and government can provide effective actions that will contribute to the formation of this future professional. Among these actions is the resolution of real cases experienced by companies using the Problem Based Learning methodology that puts the student in contact with real problems faced by companies (Lima et al., 2014).

The application of interdisciplinary projects in undergraduate courses allows for greater commitment on the part of the students, as well as greater motivation for the studies (Koch et al., 2016). The principles of the CDIO framework, as reported by Edström & Kolmos (2014), present guidelines for integrating with stakeholders both for the development and training of faculty and students.

The objective of this work is to report the experiences of partnerships between the engineering courses of a University Center in Brazil and companies and other agents, which allowed the development of practical cases for students, in addition to the approach to the labor market.

PARTNERSHIP EXPERIENCES

The Engineering courses of the University Center of Toledo Araçatuba - UNITOLEDO, located in the city of Araçatuba, state of São Paulo - Brazil, have always had an approach with the industries of the region because many professors have acted or are working in these companies. In addition many of the students of these courses work in these companies which ends up facilitating an initial contact for eventual experiences of partnerships.

In relation to related partnerships and class entities that represent the interests of industries, the Production Engineering course has been holding events in partnership with the São Paulo State Industries Center - CIESP, which has a regional office in the city.

Table 1 below presents two events and where it was possible to integrate the professionals of the industries with the teachers and students of the course.

Table 1. Events of the Production Engineering course in partnership with CIESP.

EVENT	GOALS	DATE
Optimization of Production Systems: a practical approach to the simulation of productive systems and their results in industry.	Present the partnership between CIESP and UNITOLEDO, demonstrate basic concepts of simulation and optimization and presentation of a case of success applied in an industry of the region.	October 27, 2016
Lean Board Game - Lean Production	Enable the use of tools and techniques of continuous improvement in the industrial production process.	June 20, 2017

Figure 1 presents the two events organized in partnership of the Production Engineering course with CIESP.

Figure 1. Events carried out in partnership of the course of Production Engineering and CIESP.

FRAMEWORK FOR THE DEVELOPMENT OF PARTNERSHIPS WITH INDUSTRY

For the development of partnerships with industries, the main concern has always been the realization of effective actions that generate a return to both the industries and the students of the institution. In this sense, a framework was developed to assist in the planning of actions in search of increasingly effective partnerships. Table 2 presents the steps of this framework, which was elaborated by the teachers involved in the actions.

Table 2. Framework for the development of partnerships.

STAGE PARTNERSHIP	MAIN ACTIONS AND DELIVERIES
1 – Technical Visit	In this first stage a technical visit to the industry is held so that teachers and students can learn about the processes, difficulties and challenges faced by the industry.
2 – Experience Report	In this second step, an industry manager visits the educational institution and reports their experience on some subject related to the subjects that the students are studying.
3 - Presentation of the Challenge	At this stage, the company manager presents the challenge proposed to the students, who should help throughout the semester.
4 – Work meetings	At this stage, always supervised by a teacher, students divided into teams discuss and seek a solution to the challenge presented.
5 – Challenge Resolution	In this stage, the students together with the tutor teacher, meets again with the industry manager for the presentation of the proposed solutions to the challenge.

These stages of the framework are cyclical and can be resumed according to the needs established during the resolution of the challenge, as shown in Figure 2 below.

Figure 2. Framework for the development of partnerships.

REAL CASES THROUGH PROBLEM BASED LEARNING

A practical example of partnership with the industry occurred between the course of Production Engineering and a concrete pre-casting industry where two challenges were proposed to two classes of the course. Table 3 presents the real cases to which the students were challenged.

Table 3. Real cases presented in the challenge to the students.

PRESENTATION OF THE PROBLEM SITUATION	IDENTIFICATION OF THE CHALLENGE
Concrete pre-casting company, located in the city of Araçatuba state of São Paulo, required by regulations of Brazilian law to allocate a part of its area that until then was being used to deposit finished products for demarcation of legal reserve . The products destined to the stock of finished product come from 3 lines of products that the company produces.	Develop the new layout for the finished products stock due to the demarcation of the legal reserve area.
Concrete pre-casting company, located in the city of Araçatuba state of São Paulo, needs to improve the quality of concrete pipes for sanitary sewage. The product in question is part of one of the three product lines that the company produces.	To achieve the perfect quality standard in the manufacture of concrete pipes for sanitary sewage, according to NBR 8890: 2007.

The challenge of developing the new layout for the finished products inventory was made by the group of the 5 semester of Production Engineering that used the following disciplines as a basis for the proposed solution to the problem: Layout Design and Industrial Localization, Planning, Programming and Production Control I.

The challenge of achieving the perfect quality standard in the manufacture of concrete pipes was carried out by the 7th semester of Engenharai de Produção, who used the following disciplines as a basis for the proposed solution to the problem: Management Quality and Production Planning, Programming and Control II. In both cases, the groups were organized by the professors responsible for the disciplines who assisted in the elaboration of the proposed solution to the problem, taking into account the diversification of students with different profiles for the development of the work.

Figure 3 demonstrates some of the steps taken in the technical visit to the company and the presentation of the challenges for the students of the 5 and 7 semesters of Production Engineering and some moments during the resolution of the challenges by the students in the teaching institution.

Figure 3. Challenges proposed by the industry to two classes of the Production Engineering course.

Table 4 demonstrates the CDIO Standards worked through the projects that involved two classes of the Production Engineering course and a concrete precast industry.

Table 4. CDIO Standards developed in the projects.

CDIO Standards	Description	Note
5.Design-Implement Experiences	A curriculum that includes two or more design-implement experiences, including one at a basic level and one at an advanced level	The disciplines allow each semester to elaborate integrative projects with the theme of development of new products, processes or systems.
7. Integrated Learning Experiences	Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal and interpersonal skills, and product, process, and system building skills	The integration with another course of the institution throughout the integrating project made possible the exchange of information and experiences that contributed to the development of established competencies.
8.Active Learning	Teaching and learning based on active experiential learning methods	The use of Project Based Learning enabled the use of active learning methodologies including students at the center of the teaching and learning process.
9. Enhancement of Faculty Competence	Faculty competency enhancement actions on personal / professional and interpersonal skills, and products, processes, and skills in system building	The realization of projects in partnership with companies allows a continuous training to the faculty in relation to the practices used in the company.
10. Enhancement of Faculty Teaching Competence	Teaching competency actions providing integrated learning experience, the use of empirical methods of active learning, and assessment of student learning	The realization of projects in partnership with companies allows an improvement in the development of empirical methods to be applied in the classroom.

DISCUSSION AND CONCLUSIONS

With the application of problem based learning through the challenges presented to the students of the course of Production Engineering, it is possible to validate the partnership with an industry in the region. For the realization of the partnership, a framework was elaborated by the participating professors and presented the proposal to the company in question.

Regarding the evaluation of the educational process that was discussed among teachers, industry and students, the application of problem based learning made it possible to integrate the contents of several of the course subjects, taking the subject of multidisciplinarity into the discussions of the student groups.

The case presented in this article demonstrates the contribution that active learning methodologies can provide to the improvement of the teaching and learning process and also the importance of partnerships that bring students closer to the reality of the labor market. A very important factor that has been the subject of doubts in higher education, particularly in engineering courses, is precisely the way to apply the practice along with the theory exposed in the classroom. Another issue is the development of behavioral skills such as leadership, teamwork and conflict resolution, which are just as important as technical skills and the use of active learning methodologies provide support for this development, generating better results in the teaching and learning process.

The application of new teaching and learning methods should be widely discussed with teachers and course coordinators in order to identify first what skills they intend to develop and how to identify which methodology is best applied. Alignment and training of all faculty for the use of new methodologies in the classroom is extremely important and the educational institution should provide actions that contribute to the implementation of new methodologies and resources in the teaching and learning process. The experience acquired in the application of project-based learning brought satisfactory results, which allowed several discussions between teachers and course coordinator in the methodology for application in the next semesters and also for its application in other engineering courses of the institution. Additional research should be done to identify the profile of the student entering higher education in order to assess the paradigm shift and the problem of drop-out and how the use of active learning methodologies can contribute positively to these issues.

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BIOGRAPHICAL INFORMATION

Sergio Ricardo Mazini is a coordinator and professor of the course of production engineering, holds a master's degree in production engineering. He participates in the Nucleus of Innovation and Academic Formation of the institution that is responsible for the continued formation of the teachers.

Wesley Pontes is a coordinator and professor of the course of electrical engineering, holds a PhD degree in electrical engineering.

Pedro Sergio Hortolani Rodrigues is a coordinator and professor of the course of civil engineering, holds a master's degree in civil engineering.

Lucas Mendes Scarpin is a coordinator and professor of the course of mechanical engineering, holds a master's degree in mechanical engineering.

Corresponding author

Sergio Ricardo Mazini
University Center Toledo Araçatuba
Rua Antônio Afonso de Toledo, 595
Araçatuba, São Paulo, Brazil
CEP: 16.015-270
55-18-36367083
mazini.prof@toledo.br

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A CASE STUDY DESIGNING TRAINING CURRICULA TO SUPPORT IMPLEMENTATION OF CDIO

Andrew Marchand[1], Gam Thi Hong Luong[2], Tham Thi Hong Vo[3]

[1]Department of Curriculum and Instruction, University of Victoria
[2]Office of Quality Assurance, Thu Dau Mot University
[3]Faculty of Engineering and Technology, Thu Dau Mot University

ABSTRACT

For trainers and faculty developers, helping instructors learn to design and deliver constructively aligned courses that integrate authentic, higher-order learning tasks is fundamental to implementing the CDIO framework. Encouraging instructors to change their practices and attitudes about teaching and learning, however, can be a formidable and ongoing challenge at many universities where teacher-centered instruction and passive, rote learning is common. This paper addresses this problem by sharing a case study of an ongoing Vietnam-Canada project at Thu Dau Mot University (TDMU) and Tra Vinh University (TVU), two schools that set out in 2015 to create a comprehensive set of faculty development curricula with the goals of changing teaching and learning practices and supporting the implementation of various frameworks and standards like CDIO.

Since becoming a member of the CDIO community in 2015, TDMU has been designing faculty training programs to promote active, authentic, and practical learning to support implementation of CDIO. To date, TDMU and TVU have designed an integrated framework of instructor competencies and training interventions, including seven intensive multi-day training workshops focusing on various core topics like course design, assessment design, online design and instruction, presentation skills, facilitation skills, and so on. Modeled after the Instructional Skills Workshop, a faculty training program from Canada, the training workshops analyzed in this case study were designed to help new and experienced faculty practice and authentically apply various theories, tools, and strategies that can help them implement active learning and higher-order learning-by-doing tasks.

Based on program evaluation surveys with workshop trainers and participants, this case study explores the problem of how universities can better support faculty in adopting new learning-centered practices that align with CDIO by answering several core questions, including:

- What competencies should faculty meet to be able to effectively implement CDIO in their courses?
- What training curricula best serve the needs and competencies of faculty in implementing CDIO? and
- What attitudes towards teaching and learning do faculty have, and how must these attitudes change to implement CDIO?

KEYWORDS

Faculty Development, Teaching Competencies, Training Curricula, Program Evaluation, Standards 8, 9, and 10

INTRODUCTION

Originally developed for engineering education, CDIO standards and tools have been used to support program reform in various fields by encouraging faculty to use learning-by-doing models like the CDIO design process, case-based learning, project-based learning, and problem-based learning (Johan Malmqvist, Huay, Kontio, & Minh, 2016). Even though CDIO's explicit set of standards and tools has contributed to its international popularity, implementing CDIO can be challenging within educational cultures where faculty are used to teacher-centered instruction that emphasizes transferring content via lecture rather than learning-centered instruction that emphasizes authentic practice via higher-order learning-by-doing tasks. Previous CDIO literature has addressed this challenge, demonstrating that teachers can be resistant to change when adopting the framework and highlighting the importance of effectively training and motivating teachers with carefully designed faculty development curricula (Rouvrais & Landrac, 2012).

This paper shares the experiences of Thu Dau Mot University (TDMU) and Tra Vinh University (TVU) in Vietnam, two schools which have been co-designing faculty development curricula since 2016 to support the implementation of CDIO. This paper relates TDMU and TVU's experiences developing new training curricula to serve as a case study for other institutions that are struggling to determine how they might train and support their own faculty when implementing CDIO. To achieve this aim, this paper reviews TDMU and TVU's faculty development project to date and shares the results of program evaluation surveys which were used to identify strengths and weaknesses of the training program as well as possible future curricular improvements that might better support CDIO implementation.

PROJECT OVERVIEW

The impetus for TDMU and TVU's training program began in 2015 when TDMU staff were tasked with implementing a comprehensive program that would help the university meet the goals and standards of various international frameworks and quality assurance organizations like CDIO and AUN-QA. Since then, TDMU and TVU have worked in partnership to design a training program that currently consists of manuals and facilitator resources for seven different multi-day workshops, with a further four multi-day workshops in development.

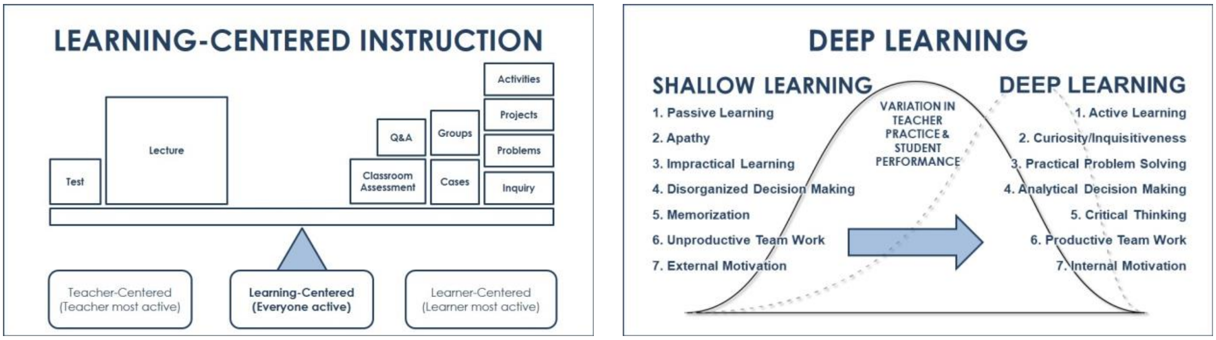

Figure 1: Theoretical Foundations for Program Design

Illustrated in the figure above, two concepts were identified at the beginning of the design process to act as theoretical foundations that might help designers integrate the program's curricula and help faculty quickly envision why the training program is necessary. As TDMU and TVU's educational culture often stresses lecturing and testing, the concept of *learning-centered instruction* was useful in helping designers and faculty understand the need to balance teacher-centered methods with active learning and learning-by-doing strategies. Similarly, the concept of *deep learning* was also useful in helping designers and faculty understand the need to shift student and teacher attitudes and behavior away from rote, passive learning and towards higher-order, authentic learning.

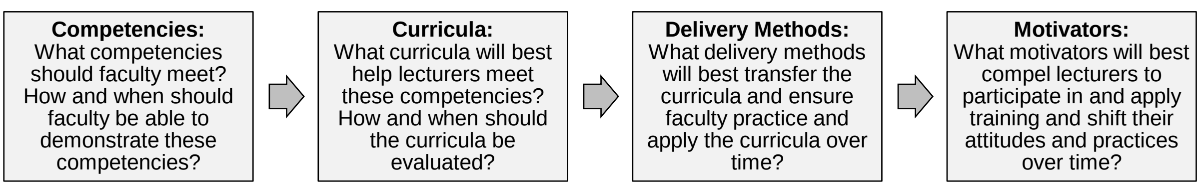

Figure 2: Core Questions Guiding Program Design

After defining foundational concepts to guide the design process, project staff identified several core questions related to the program's targeted competencies, curricula, delivery methods, and motivators. The sections that follow provide an overview of the design decisions that have been made to date with regard to these elements and questions.

Instructor Competencies

Determining faculty competencies that align with university objectives for teaching and learning is an important early step in designing a faculty training program. In 2016, TDMU and TVU began developing a competency framework for faculty with the goals of:

a) Identifying all of the skills and competencies lecturers should have at various professional levels or stages in their careers;
b) Reviewing and adapting these competencies to encourage lecturers to shift away from traditional, lecture-based instruction towards learning-centered methodologies and higher-order application tasks; and
c) Aligning these competencies with international standards and frameworks like CDIO and ASEAN University Network-Quality Assurance (AUN-QA) to support TDMU and TVU's future accreditation efforts.

To achieve these goals, TDMU and TVU drafted a framework of instructor competencies that were designed by writing competency statements, linking these statements to literature from international frameworks and standards organizations like CDIO, and describing different levels of achievement for each competency that faculty might demonstrate over their careers. Summarized in Appendix 1, the current framework contains 33 competencies categorized into five themes including general professional skills, learning design skills, instructional skills, assessment skills, and technological skills. Table 1 below illustrates a detailed example of one competency statement related to active learning.

Table 1: Detailed Competency Statement for Active Learning

Competency Statement	• Lecturer demonstrates effective use of various active learning strategies and tasks during class time
Related Standards	• Lecturer ensures that teaching and learning based on active experiential learning methods like small-group discussions, demonstrations, debates, concept questions, etc. (Worldwide CDIO Initiative, 2018)
Criteria Levels	• Beginning Instructor: is aware of competencies and standards related to active learning like those above; designs, uses, and improves various active tasks that allow learners to practice using curricular skills, concepts, and values; • Experienced Instructor: meets beginning criteria above; evaluates and chooses most effective activities and tasks for given aims, outcomes, situations, and learners; listens to learner needs and feedback to improve strategies for active learning; provides support to other lecturers in designing and using effective active learning tasks; • Department Head: meets experienced criteria above; evaluates and guides lecturers in designing and using effective active learning tasks.

As illustrated in Appendix 1, while the majority of the competencies make sense in most instructional contexts, some competencies were specifically written to ensure faculty would learn skills that would support for CDIO implementation. For example, statements were written related to designing learning-by-doing tasks, planning for active learning, integrating program curricula, blending instruction, supporting meta-learning, and so on.

Training Curricula

After identifying an initial framework of competencies, curriculum designers then considered what curricula could be used to help faculty most efficiently and effectively meet these competencies. TDMU and TVU staff explored existing training curricula and delivery models used in universities to support similar competencies for faculty. One model explored that was already in use at TVU was the Instructional Skills Workshop (ISW). ISW is a Canadian training program consisting of multi-day workshops that require faculty to give and receive peer feedback while they deliver micro-lessons demonstrating active learning strategies and outcomes-based instruction. Designed by Douglas Kerr and Diane Morrison in 1978 for Vancouver Community College, ISW has been supported and improved over the last 40 years by an informal network of trainers and facilitators who have shared the program with different colleges and universities in more than 30 countries to date (ISW Network, 2018). The training program was originally introduced to Vietnam in 2009 at Tra Vinh University, and TVU supported TDMU in implementing ISW in 2015.

The ISW program consists of two core workshops—Instructional Skills Workshop and Facilitator Development Workshop (FDW)—which are each usually delivered over four days and five days respectively. ISW is a prerequisite for FDW, and participants who complete FDW are certified to conduct their own ISW workshops. Both ISW and FDW require participants to microteach, but while ISW focuses on helping participants apply behaviorist and constructivist lesson planning models, FDW focuses on helping participants apply various group facilitation strategies. Although the workshops are reasonably flexible in how they can be delivered and what curricula is included, both workshops are standardized across institutions by manuals supplied by the ISW Network as well as a series of requirements for the workshops' delivery. For example, ISW workshops must be at least 24 hours, provide three opportunities for participants to microteach, and provide peer feedback to participants on their teaching that is communicated verbally, in writing, and with video (ISW International Advisory Committee, 2006a, 2006b).

When exploring ISW as a potential training model to support the implementation of CDIO, TDMU identified several strengths and weaknesses for ISW, which are listed in the following table. Based on the identified weaknesses, it became clear that although ISW supported key competencies relevant to CDIO implementation, the core workshops needed to be adapted to better meet TDMU and TVU's specific needs and support a larger competency framework.

Table 2: Strengths, Weaknesses, and Required Adaptations of ISW Core Curriculum

Strengths	**Weaknesses**	**Required Adaptations**
Existing curricula focusing on active learning, outcome-based instruction, valid assessment, etc.	Insufficient curricula in its core program to meet a comprehensive set of faculty competencies	Design new curricula that integrates with ISW but meets more competencies
Existing curricula supported by an international network of facilitators and institutions	Foreign curricula that may not always be culturally appropriate in Vietnam context	Evaluate and adapt existing curricula to ensure it is culturally appropriate to local needs
A participatory delivery model that encourages application and demonstration of learning	Low facilitator-participant ratio (usually 1:6) so lots of finances/time for large-scale implementation	Adopt a delivery model that allows for larger groups of faculty to easily participate at the same time
Well-structured workshop schedule and resources that are easy to adapt and implement	Emphasis only on large workshops for delivery of training curricula	Explore additional delivery models besides long, face-to-face workshops

Further elaborated in Appendix 2, TDMU identified nine additional workshops that might be designed and integrated with the core ISW and FDW workshops to meet a more comprehensive set of competencies. Using the curriculum development process illustrated in the figure below, TDMU and TVU have designed five of the nine planned workshops to date, including Assessment Design Workshop, Course Design Workshop, Presentation Skills Workshop, Online Instructional Skills Workshop, and Online Course Design Workshop.

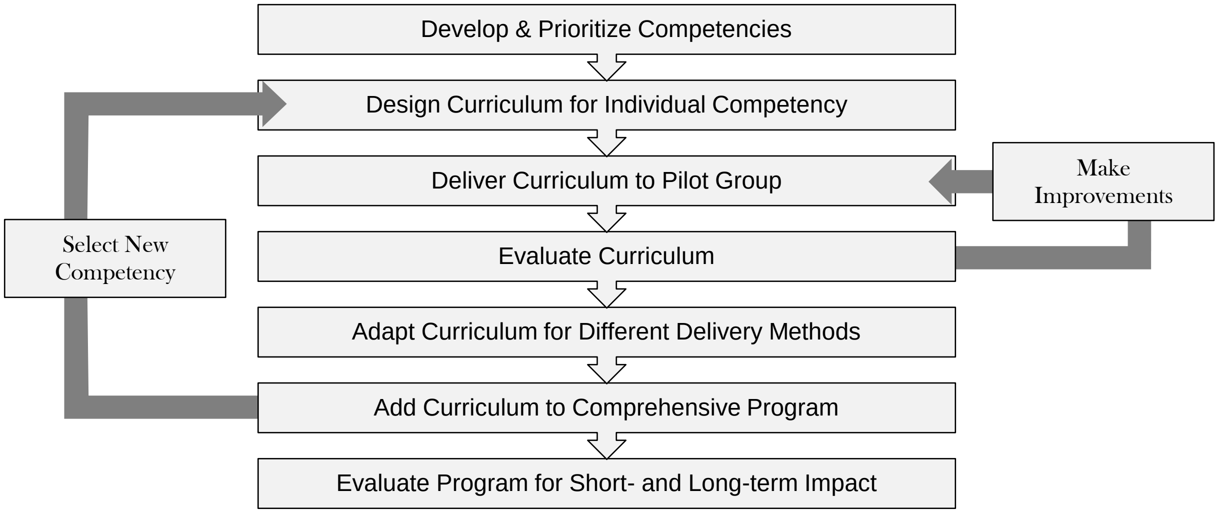

Figure 3: Curriculum Development Process for Additional Training Interventions

The additional workshops are modeled after ISW in that they require participants to not only learn theories and skills related to targeted competencies but also apply those theories and skills by creating and sharing authentic products and performances and receiving feedback from their peers. Rather than teach mini-lessons like in ISW, for example, participants in the Assessment Design Workshop must design, present, and receive feedback on assessment products that they will use in their teaching, including a test blueprint with example test questions, an assignment rubric, and a self- or peer-assessment activity.

To more explicitly support CDIO implementation, some of the new workshops require participants to use planning tools and templates promoted in CDIO literature. For instance, the Course Design Workshop requires participants to design, present, and receive feedback on a course map, a course syllabus template, a course syllabus, and a course assessment template (Doan & Nguyen, 2014; J. Malmqvist, Östlund, & Edström, 2006). Similarly, the Program Design Workshop, which is currently in development, requires participants to present completed templates, including the program's curriculum structure, curriculum matrix, and assessment model (Doan & Nguyen, 2014; J. Malmqvist et al., 2006). Appendix 2 further describes the types of products and performances participants must present in each of the workshops currently designed.

Program Implementation and Delivery

After TVU supported 12 TDMU staff in becoming certified ISW facilitators in 2015, both universities had staff who could facilitate workshops using the ISW training model, allowing TDMU and TVU to begin designing and piloting the additional curricula throughout 2016 and 2017. The following table lists the workshops that have been designed to date as well as the extent of their implementation at both schools.

Table 3: Implementation of Faculty Training Program at TDMU and TVU*

Assessment Design Workshop (ADW)	• Designed in 2017 with translation support from TDMU • Piloted in 2017 at TDMU, with 47 participants to date
Course Design Workshop (CDW)	• Completing design in first quarter of 2018 with translation support from TDMU • To be piloted at TDMU mid-2018
Facilitator Development Workshop (FDW)	• Offered at both TDMU and TVU • 33 participants from TDMU, and 15 participants from TVU
Instructional Skills Workshop (ISW)	• Offered at both TDMU and TVU • 106 participants from TDMU, and 57 participants from TVU to date
Online Course Design Workshop (OnCDW)	• Designed in 2017 with translation support from TDMU • 47 participants from TDMU, and 167 participants from TVU to date
Online Instructional Skills Workshop (OnISW)	• Designed in 2017 with translation support from TVU • To be piloted in 2018 at TVU
Presentation Skills Workshop (PSW)	• Designed in 2016 with translation support from TVU • Piloted at TVU, with 27 participants in total to date

*Participant totals as of January 2017

To remedy the identified weaknesses of ISW core curriculum, workshop facilitators experimented with different adaptations during the program's initial implementation, including:

- Having multiple staff facilitate ISWs to support larger groups (e.g. 3 facilitators for 21 participants), where curricula is taught to a large group, after which individual facilitators simultaneously support participant presentations and feedback in small groups;
- Having critical discussions during the workshops about the appropriateness of the curricula with regard to school's goals and cultural context;
- Adding introductions to translated workshop manuals that help participants reflect on the curricula's appropriateness with regard to school's goals and cultural context; and
- Having discussions about how workshop curricula can be adapted for blended delivery to reduce face-to-face workshop hours.

PROGRAM EVALUATION

Having provided an overview of TDMU and TVU's faculty development program to date, this section shares the methods and results of surveys conducted in early 2018 at TDMU to evaluate the design and delivery of ISW and FDW core curricula and further explore how new workshop iterations and adaptations can better support faculty in implementing CDIO.

One survey was conducted in early 2018 which was designed to gather feedback from ISW facilitators at TDMU, a group totaling 33 instructors and staff who participated in the ISW and FDW core workshops between 2015 and 2017. The aim of surveying this specific group was to gather data from respondents who had experienced all of ISW's core curricula and could therefore provide informed feedback on what core curricula should be changed or what supplementary training should be added.

Out of the total of 33 instructors and staff who completed ISW and FDW at TDMU, 30 responded to the survey during a meeting where researchers explained the purpose of the survey and answered participant questions, after which respondents completed the survey in-person using an online form. Open-answer responses were then coded into categories for quantification and ranking, while Likert-scale responses were scored and ranked for comparison and analysis.

The aims of the survey questions were to gather feedback on participants' and facilitators' reactions to, learning from, and behavioral change after completing ISW and FDW. Questions were designed to target four general areas of inquiry, including:

1. What participants remember and apply most from their past ISW and FDW training,
2. How much participants think ISW and FDW training changed their understanding of targeted competencies relevant to CDIO,
3. What participants define as their training needs and preferred delivery methods, and
4. What attitudes participants have towards teaching-centered and learning-centered instruction.

Memory and Application of ISW Training

When the group of 30 respondents was asked open-ended questions about what they remember and apply most from their training, 23 of the participants stated that they remember and use new lesson planning models. ISW curriculum uses the two acronyms BOPPPS and CARD to help participants more easily remember key elements of behaviorist and constructivist lesson planning models (ISW International Advisory Committee, 2006b). Although 23 participants specifically referenced these acronyms, the survey did not gather feedback on how and how often these models were used, nor what effect their use had on student learning.

In addition to using new lesson planning models, 18 of the 30 participants stated that they remember and apply new teaching strategies and skills from their ISW training. 13 of these respondents wrote generally about the strategies they learned—for example, that they learned new methods for supporting team work, providing feedback, activating learners, or creating a positive learning environment—while only five made reference to specific teaching strategies sometimes demonstrated in ISW, including graffiti, fishbowl, role play, placemat, and group agreement activities.

In addition to learning new planning models and instructional skills, a third major theme in the responses related to affective outcomes from the ISW training. Eight of the 30 respondents stated that their ISW and FDW training helped them emotionally or relationally, for instance, by feeling friendship, attachment, and/or connection with other participants, by enjoying learning from their colleagues, by appreciating the workshop's fun atmosphere, or by feeling a new sense of sincerity and enthusiasm towards teaching.

Understanding of CDIO-related Competencies

The group of 30 participants was asked about ISW and FDW outcomes that are more related to supporting CDIO implementation, including using outcomes, using active learning strategies, teaching critical thinking, and ensuring practical application of curriculum. Illustrated in the table below, most respondents indicated that they experienced a large or very large change in their understanding related to these four outcomes. Although this suggests that most respondents felt positively about meeting these outcomes, more than a quarter of respondents indicated that they experienced no change or a small change in their understanding of how to teach critical thinking or how to ensure practical or authentic application of curriculum.

Table 4: Perceived Impact of ISW Training Targeting CDIO-related Competencies

Targeted Competency	No Change	Small Change	Large Change*	Very Large Change*	Articulated Responses
Outcomes	0	2 (7%)	21 (70%)	7 (23%)	17 (57%)
Active Learning Strategies	0	0	26 (87%)	4 (13%)	17 (57%)
Critical Thinking	0	8 (27%)	21 (70%)	1 (3%)	17 (57%)
Practical/Authentic Application	3 (10%)	6 (20%)	15 (50%)	6 (20%)	13 (43%)

*Categories were moderate/large in English, but translated to large/very large in Vietnamese for final survey

Participants were also asked open-ended questions about how ISW and FDW training improved their understanding of the four outcomes. For the first three outcomes, 17 of the 30 respondents articulated clear answers that specifically detailed how ISW changed their practice, while only 13 articulated clear answers for the fourth outcome. This lack of articulated responses indicates that although most participants felt they underwent a large change in their understanding, only approximately half were willing or able to articulate the change.

Training Needs and Preferred Delivery Methods

Besides providing data on the impact of core ISW and FDW training, the 30 respondents also provided feedback on the training they feel they need and the delivery methods they feel would be most convenient. The aim of assessing participant needs was to determine what topics should be integrated into new training curricula and what other delivery methods might be as or more effective than ISW's multi-day workshop format. For the needs assessment component of the survey, the respondents completed Likert matrices that allowed 18 training topics and 12 delivery methods to be scored and ranked from most to least needed or desired.

Ranked from most to least needed, the 18 training topics included in the survey were student motivation, lesson planning, assignment design, subject matter knowledge, active learning, learning-by-doing, test design, course planning, fostering supportive classroom environments, classroom technologies, needs assessment, blended/online learning, meta-learning, course syllabus design, management of classroom behavior, learning outcomes, feedback, educational theory, and student-teacher relationships. In addition, the 12 delivery methods included in the survey, ranked from most to least desired, were mentoring, online modules/courses, informal groups, printed or digital handouts, borrowable or downloadable books, short (multi-hour) workshops, observation of others' classrooms, long (multi-day) workshops, one-on-one consultations, attending conferences, multi-course graduate certificates, and personal feedback from classroom observation.

One implication of these rankings is that long workshops are much less desired by faculty compared to other training methods. Since long workshops ranked eighth out of 12 different types of training methods, the delivery of future training interventions should be more varied than ISW's multi-day workshop model, focusing on informal and independent means of learning.

Attitudes Towards Learning-centered Instruction

As discussed above on page 2 and illustrated in Figure 1, the training program's designers used the concepts of *learning-centered instruction* and *deep learning* to guide curricular decisions and communicate the need for new workshops. The final area of inquiry in the program evaluation was to measure faculty attitudes towards learning-centered instruction to see if and how much faculty would be motivated to participate in new training and change their practice to support CDIO implementation.

A Likert matrix with 11 statements was included in the survey to gauge respondents' agreement with teacher-centered practices that encourage shallow learning and learning-centered practices that encourage deep learning. Teacher-centered statements were structured so that the teacher was the primary actor in making curriculum choices, transferring content, conducting learning activities, and solving problems. Learning-centered statements were structured so the student was the primary actor in solving problems, influencing the outcomes and methods of instruction, and learning through independent practice.

Table 5: Participants' Agreement with Teaching-centered and Learning-centered Statements

Statements	Strongly Disagree	Disagree	Agree	Strongly Agree
Learning-centered Statements (5 total)	0.4 (1%)	2.0 (7%)	11.0 (37%)	16.6 (55%)
Teaching-centered Statements (6 total)	9.0 (30%)	8.7 (29%)	9.5 (32%)	2.8 (9%)

After averaging the responses from each type of statement, 92% of respondents agreed or strongly agreed with learning-centered statements while only 41% agreed or strongly agreed with teaching-centered statements. The responses illustrate that although many still value teacher-centered instruction, the majority of respondents have a positive attitude towards learning-centered instructional practices, implying that most would see value in future training that helps them implement active learning and learning-by-doing strategies to support CDIO implementation.

SUMMARY REFLECTIONS ON DESIGNING TRAINING FOR CDIO

This overview and evaluation of TDMU and TVU's emerging faculty development program illustrates how two universities have adopted and begun modifying existing training curricula to support implementation of CDIO. For other universities wanting to design faculty training for CDIO, this case study raises several important considerations related to existing training models, competencies, needs assessment, delivery methods, and ongoing program evaluation.

- Using existing training models: A great deal of curricula exists that align with CDIO objectives. TDMU and TVU's experience with ISW illustrates, however, that universities need to be careful in adopting and adapting existing curricula to ensure they meet competencies relevant to university goals and CDIO as well as the needs of faculty.
- Using competencies for curriculum design: Competency frameworks support a deductive approach to curriculum design that helps to ensure that training interventions align with a comprehensive set of instructor skills, integrate with and complement each other, and support faculty and program evaluation. Aligning competencies with CDIO standards and literature helps provide evidence that faculty training programs support CDIO implementation.
- Using needs assessment for curriculum design: Needs assessments support an inductive approach to curriculum design that helps to ensure that training interventions prioritize curricula based on what faculty need and use the most

appropriate delivery methods. TDMU and TVU's experience illustrates that evaluating the needs of faculty helps to find gaps in current training that can be addressed in future iterations of curricula.

- Varying delivery methods: Once curriculum is selected for a training program, designers must carefully consider how that curriculum is taught or shared with faculty. TDMU and TVU's experience illustrates that although ISW's participatory workshop model helps faculty practice core theories and skills, participants prefer informal and independent methods of delivery.
- Conducting ongoing evaluation: Ongoing evaluation is integral to ensuring that training programs effectively support faculty in gaining increasing mastery of targeted competencies throughout their careers. TDMU and TVU's program evaluation illustrates that surveying faculty can yield data about what faculty learn from past training, what they want to learn in future training, and how much they value different approaches to instruction. The program evaluation also illustrates that it can be hard to measure how much faculty apply training curricula in their classrooms, and if their training has any effect on student learning.

In conclusion, to help other universities learn from their experience, this paper has demonstrated how two universities have begun working in partnership to solve the problem of implementing CDIO in an educational culture that traditionally prioritizes teacher-centered instruction. There are, of course, a great many related challenges that need to be addressed as the training project progresses, including:

- Partnering with other universities to share the program and learn new curricula and delivery methods that might improve on and integrate with it;
- Completing the comprehensive set of curricula that aligns with CDIO and other standards while meeting the expressed needs of local faculty;
- Motivating more faculty to invest the extra effort and time required to participate in and meaningfully apply the new training; and
- Continuously evaluating the application and impact of the program to make ongoing improvements and clearly link it with progress towards CDIO goals.

To address these challenges, TDMU and TVU will continue their partnership to achieve CDIO standards by developing and piloting curricula until a comprehensive program is designed that effectively supports faculty in shifting TDMU and TVU's educational culture towards learning-centered instruction and deep learning. Given the positive feedback and participation rates of ISW, both universities will continue modeling new training interventions after ISW's workshop format with the addition of supplementary curricula and delivery methods that might better meet faculty's ongoing needs for training.

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BIOGRAPHICAL INFORMATION

Andrew Marchand, a PhD Candidate at the University of Victoria, is an educational consultant and instructor who specializes in faculty development, curriculum design, and online instruction. He has worked with various universities in Canada, Vietnam and Ghana and is the author of multiple training workshops and programs currently in use at different universities. His current research focuses on post-colonial approaches to cross-border educational sharing.

Gam Thi Hong Luong obtained her PhD from Southern Cross University, Australia. Her current research focuses on student assessment in higher education, quality assurance, change management and professional development. She is Deputy-Head, Office of Quality Assurance, Thu Dau Mot University.

Tham Thi Hong Vo is a PhD candidate at Lac Hong University, Vice Head of the Department of Information Technology, Faculty of Engineering and Technology, Trainer of Institute for Strategic Development at TDMU, Binh Duong, Vietnam. Her current research focuses on data mining, information management, and developing teaching methodology training programs.

Corresponding author

Andrew Marchand
Thu Dau Mot University (Vietnam) & University of Victoria (Canada)
06 Trần Văn Ơn St, Phú Hòa Ward,
Thủ Dầu Một City, Bình Dương Province, Vietnam
armarcha@uvic.ca

APPENDIX 1: SUMMARY OF COMPLETE COMPETENCY FRAMEWORK

COMPETENCY THEME	COMPETENCY STATEMENTS
PROFESSIONAL SKILLS	
Growth & Development	Demonstrates commitment to continuous professional growth
Self-evaluation	Objectively self-evaluates professional skills and competencies
Educational Theory	Maintains up-to-date knowledge of educational theory and applies it to their instruction
Subject Knowledge	Maintains up-to-date theoretical knowledge and practical field experience within subject area
Ethics	Adheres to professional and legal standards of ethics
LEARNING DESIGN SKILLS	
Outcomes & Competencies	Uses outcomes during lesson and course design to align with course, program, and professional competencies
Needs Assessment	Evaluate learner needs, abilities, and motivations when designing lessons and courses and makes modifications to curriculum or delivery methods when necessary
Lesson Design	Designs lessons to maximize learning and align with course competencies/outcomes using varied instructional techniques, learning activities, and assessment tasks
Course Design	Designs engaging and challenging courses with sequenced lessons that build towards higher-order competencies and authentic application of course skills, knowledge, and values
Blended Design	Designs courses that utilize eLearning to reduce in-class lecturing and increase learners' in-class authentic practice
Syllabus Design	Write clear and accessible course syllabi that guide student expectations, behaviour, and learning during the course
Universal & Personalized Design	Make courses as accessible and engaging as possible to the widest variation in learner abilities, backgrounds, and styles
Design for Learning-by-doing	Design larger authentic tasks that require learners to reflect on, practice, and apply higher-level skills and thinking
Integrated Design	Integrates their courses and lessons with other courses in their learners' program
Design for Student Portfolio	Design product or performance assessments for learners to include in their portfolios for integration of learning and future employment
INSTRUCTIONAL SKILLS	
Motivation & Engagement	Stimulates and sustains learner motivation and engagement throughout courses and lessons
Learner-Teacher Relationships	Develop respectful, productive, and empowering relationships with learners based on clear communication, roles, and responsibilities
Learning Environment	Creates productive, cooperative, and supportive learning environments that help learners feel relaxed and safe
Active Learning	Uses various active learning strategies and tasks during class time
Meta Learning & Learning Skills	Teaches learning skills and strategies in addition to curricular content to help learners improve their own learning processes
Presentation Skills	Demonstrates effective verbal, written, visual, and physical communication skills when presenting curriculum
Facilitation Skills	Uses effective facilitation strategies during collaborative activities, tasks, and discussions
Questioning Skills	Use questioning techniques during instruction to probe for critical thinking and target different learning levels and domains
Classroom Management	Uses varying classroom management techniques that respect learners and maintain a productive learning environment
ASSESSMENT SKILLS	
Formative Assessment	Uses of varying classroom assessment techniques to gauge learner understanding
Feedback	Provides rich and personalized feedback to learners during activities and assignments
Test Design	Designs valid and reliable tests that align with and target desired outcome domains and levels of learning and use appropriate question types
Rubric Design	Create valid and reliable rubrics that support teacher's and learner's evaluation of assignments
Peer- & Self-assessment	Uses peer- and self-assessment strategies during activities and/or assessments
TECHNOLOGICAL SKILLS	
Information Technologies	Uses appropriate technologies to manage information, learning resources, and student data
Visual Aids	Creates and modifies effective visuals for use as instructional aids, including PowerPoint presentations, photographs, illustrations, diagrams and charts
Online & Learning Management Systems	Uses Learning Management Systems, ePortfolio systems, blogging systems, and other online tools to support instruction and professional development
Online Lecture Production	Uses video recording and production tools to create effective lectures for online or blended

APPENDIX 2: DESCRIPTIONS OF MULTI-DAY WORKSHOPS

Assessment Design Workshop (ADW)	Participants learn to design test blueprints, tests, rubrics, and other assessment tools that align with course competencies and outcomes. ADW focuses on validity and reliability, instructional alignment, test question types, test blueprints, learning-by-doing assignments, rubrics, scoring sheets, self- and peer assessment, etc. Participants must design and present a test blueprint, rubric, and self- or peer-assessment tool and receive feedback from their peers.
Course Design Workshop (CDW)	Participants learn to develop course outcomes, course maps, and course syllabi, focusing on such themes as sequencing lessons, incorporating learning-by-doing strategies and assessments, designing for varying learner abilities and styles, and so on. Participants must design a comprehensive course syllabus and course map and revise them after receiving feedback from their peers.
Facilitator Development Workshop (FDW)	Participants learn to facilitate ISW, as well as the above workshops if they wish to apprentice further with facilitators. Participants must present three mini-lessons and facilitate feedback for three other participants. FDW requires completion of ISW before participants can register.
Instructional Skills Workshop (ISW)	Participants learn to practice lesson planning and instruction that focuses on active learning, by reviewing outcomes-based lesson planning models, delivering three videotaped micro-lessons, and receiving peer feedback from their colleagues
Learning-by-doing Workshop (LBD)	Participants learn how to plan lessons and larger projects that promote learning by doing using models like case-based learning, problem-based learning, project-based learning, inquiry-based learning, and CDIO. Participants must design a comprehensive assignment using one of these strategies (e.g. write a case; design a problem assignment; design a project assignment; design an inquiry assignment; design a design-implement assignment), and revise the assignment after receiving feedback from their peers.
Narrative Skills Workshop (NSW)	Participants learn how to tell stories to highlight core concepts and values and to engage learners. NSW focuses on storytelling techniques, narrative structure, and how and when to use story in the classroom. Participant must plan and deliver three short educational stories and receive feedback from their peers.
Online Course Design Workshop (OnCDW)	Participants learn to structure online lessons and course websites to maximize learner usability and success when teaching online or blended. OnCDW focuses on online course site structure, course and lesson outcomes, online learning activities, online assessment, supporting online learners, using learning management systems, designing blended instruction, planning learning-by-doing assignments, etc. Participants must design online lessons in Moodle and revise them after receiving feedback from their peers.
Online Instructional Skills Workshop (OnISW)	Participants learn to design and deliver video lectures for online delivery. OnISW focuses on lesson planning, designing quality visual aids, video capture and production, using learning management systems, and supporting online learners. Participants must design online video lectures and revise them after receiving feedback from their peers.
Presentation Skills Workshop (PSW)	Participants learn to design and deliver effective presentations, focusing on audience assessment, engagement strategies, presentation structure, facilitating questions and discussions, physical and visual communication, etc. Participants must plan and deliver short presentations and receive feedback from their peers.
Professional Portfolio Workshop (PPW)	Participants learn how to create and maintain a professional teaching portfolio, focusing on such themes as structuring and designing ePortfolios, writing teaching philosophies, collecting and reflecting on teaching artefacts, self-evaluating professional competencies, and so on. Participants must design and present a teaching portfolio and teaching philosophy, and receive feedback from their peers.

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FROM GROUP TO INDEPENDENT PROJECT WORK: DOES CDIO PREPARE LEARNERS?

Laura J Leslie[1], Paul C Gorman[2], Sarah Junaid[1]

1 Mechanical Engineering and Design, Aston University. 2 Department of Market Research, Aston University, Birmingham, UK

ABSTRACT

The aim of this research was to investigate the effectiveness of group project-based-learning (PBL) CDIO based modules, in years 1 and 2 of study, on student's skills and competence levels in their individual Final Year Projects (Projects). The question is whether students are able to transfer skills from the group based environments to individual Projects. Two questionnaires (QNRs) were given to Project students; a pre-project questionnaire (QNR1) and a post-project questionnaire (QNR2), to gauge self-awareness of project planning, skills confidence, independence, and the importance of their Project advisor. Following completion of their Projects, students were also invited to participate in focus groups. QNR1 and QNR2 were completed by 37 (45% of cohort) and 36 students (43%) respectively, 13 of which were paired responses between the QNRs. Seven students attended focus groups for further discussion. Results from QNR1 suggested students felt a high level of responsibility for all phases of their Projects, however, they also indicated a reliance on their advisors (QNR2), which suggests they are not always confident with individual work. Focus groups also suggested that some students found the transition from group work to an individual project challenging. QNR1 students perceived themselves as good planners, though by QNR2 that perception had decreased, with 14% of students indicating that they always 'ran behind'. Our results suggest that our CDIO programmes do equip students with confidence in a variety of key skills, including independence and ownership of project work. The results also suggest that there is a need to further develop these skills, including time management, and to ensure students' confidence is a true reflection of competence. It has also indicated that programmes should be designed to more effectively aid students in the transition from group to individual project work.

KEYWORDS

Independence, Project-based-learning, Problem-based-learning, Mechanical Engineering, Standards: 1, 2, 3, 5, 7, 8, 10, 12

INTRODUCTION

CDIO (Conceive, Design, Implement, Operate) was developed in order to provide a framework for engineering educators to enable students to have the correct knowledge and skills to become successful engineers (CDIO, 2018; Crawley, Malmqvist, Lucas, & Brodeur, 2011). In the department of Mechanical Engineering and Design at Aston University, programmes are designed around the principles of CDIO, underpinning four major project-based-learning (PBL) modules delivered in the first two years of study. In these modules, students work in groups on various projects such as the design-build of an electric race car, a functioning wind turbine, an electronic healthcare device, and a 3D printed pneumatic actuator and valve. The aim of these programmes is to equip students with a range of technical and professional skills to help make them industry-ready. Indeed, active learning in Undergraduate STEM programmes has been shown to increase students concept knowledge (Freeman et al., 2014), something which our programmes aim to do.

Measuring student's skills and their perception of their skills is an important tool in understanding how they learn and whether delivery of material is suitable. Previous studies have shown this to be used to aid in student retention (Besterfield-Sacre, Atman, & Shuman, 1998), course delivery (Grant, Malloy, & Murphy, 2009) and staff-student interaction (Bjorklund, Parente, & Sathianathan, 2004).

However, as educators, it can be difficult to measure how successful programmes are in equipping students in certain skills, particularly once students leave the education system and we are no longer assessing them. In the Final Year of study on our programmes, students undertake an individual Project with support from an academic 'advisor'. The Project can be of the students own design, or chosen from a list of varied Projects linked to the academic's research groups and interests. The transition from tutor lead group PBL modules to individual Projects was seen to be a suitable juncture at which to attempt to measure students skills and perceptions.

The aim of this study was to ascertain the effectiveness of the four group PBL modules in the preparation of students taking on their individual Projects. In doing so, we wished to explore the following:

- Independent working: students' perceptions of working independently and of the role of their academic project advisor
- Skills: students' confidence in a range of technical and professional skills such as time management.

MATERIALS AND METHODS

Questionnaires

Two questionnaires (QNRs) were developed with the intention of obtaining both qualitative and quantitative data. The first QNR was delivered to students in week 3 of Teaching Period 1 (TP1) when students were just beginning their Projects (QNR1), and the second in week 24 of TP2 when students had completed their Projects (QNR2). Each contained questions on a variety of topics, only some of which are explored in this study. The question topics investigated in this study and the theme that each addressed are shown in Table 1**.**

Table 1. The question themes in QNR1 and QNR2 alongside the associated areas of interest.

	QNR1 – Pre-Project	QNR2 – Post-Project
Independence	Anticipated responsibility between student and advisor on stages of the Project	Importance of advisor on stages of the Project
Independence & Skill: Time Management	Planned frequency of meetings with the Project advisor	Actual frequency of meetings with the Project advisor
Skill: Planning	The ability to plan	Retrospective look at planning
Skill: Time Management	Anticipated time spent on the Project across the two teaching periods (TP1 and TP2)	Actual time spent on the Project across the two teaching periods (TP1 and TP2)
Skill: Various	Confidence in a variety of skills and abilities (technical and professional)	Confidence in a variety of skills and abilities (technical and professional)
Role of CDIO		Use of CDIO phases in delivery of Project

Focus Groups

Focus groups were made available to all Project students via email invitations. Three groups were run by a researcher unconnected to the course, meaning that the students could feel more comfortable to discuss issues regarding their experiences. Confidentiality was assured, and a total of seven students attended. As an incentive to attend, respondents were given a voucher after participating in a focus group.

RESULTS

Independence – Working with a 'Project Advisor'

Students were asked in QNR1 who they felt would be primarily responsible for the different phases of their Project. The results from this question are shown in Figure 1 and reveal that for all phases of the Project past the Definition phase, the majority of students felt that it was they themselves who held responsibility. In particular, project planning and report writing scored highest with 95 % and 97 % of students respectively identifying these phases as primarily their responsibility. In QNR2, students were asked how important they found their project advisor in the same phases of the Project. The results from this question, shown in Figure 2, suggest that many students found their advisor important in all aspects of the project. 78 % of students felt the advisor was important for defining the project and 69 % for implementing the project. The only phase in which there was a divided answer was in the writing phase, with 42% of students not finding the advisor important and 47% finding them important. To assess changes in individual responses, the paired data was analysed (n = 13). To check for bias, the paired data was compared to this overall data and the distribution of responses was found to be representative. In terms of time spent meeting the advisor, there was a mixed change in the response when comparing the frequency the students *planned* to see their advisor compared to the frequency they *actually* met their advisor (Figure 3).

In the focus groups conducted, students discussed that the experience a student had with an advisor depended very much on both the type of Project undertaken, and on the personality and availability of the academic.

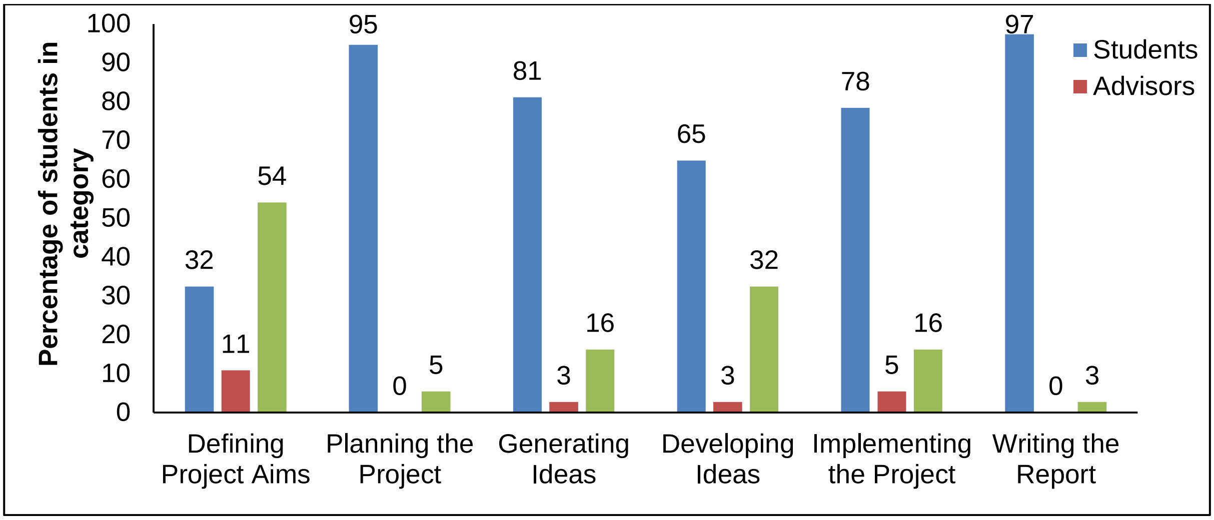

Figure 1. QNR1 data (n=37) asking students who they felt would be responsible for the different aspects of the Project stages

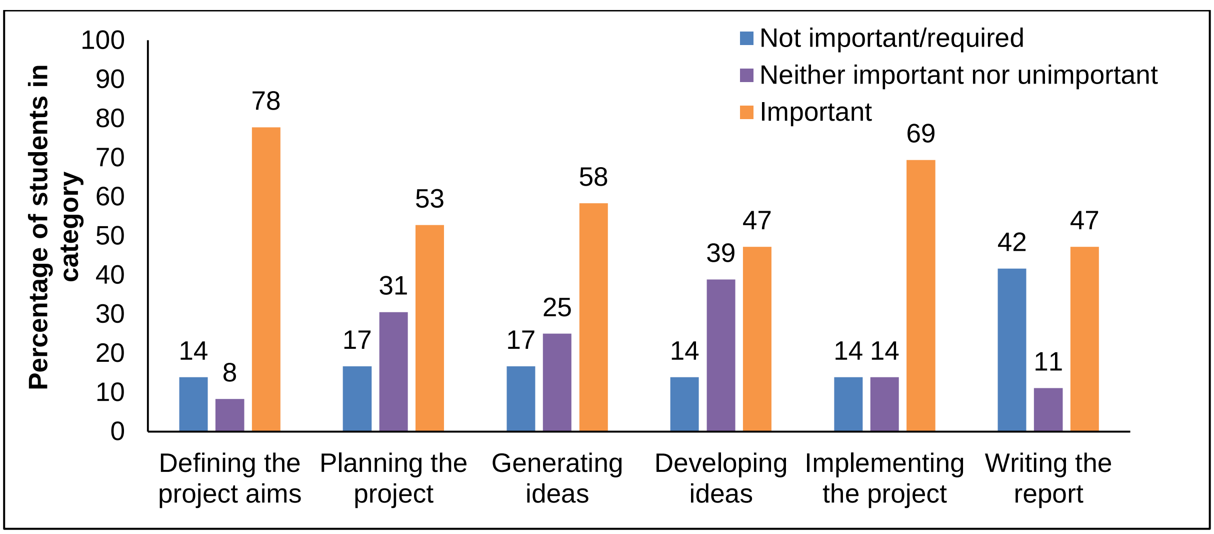

Figure 2. QNR2 data (n=36) asking students how important they found their Project advisors to be in the different Project stages

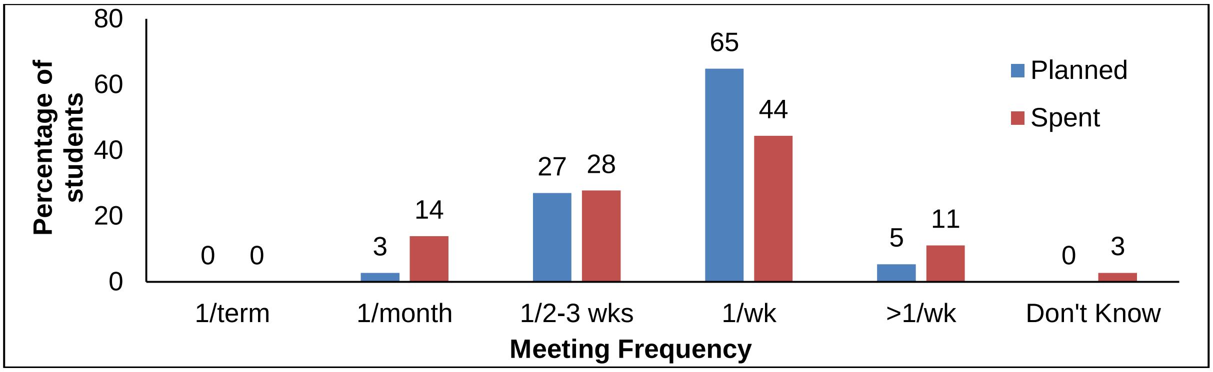

Figure 3. Comparison of data from QNR1 (Planned frequency of meetings with advisor) and QNR2 (Actual frequency of meetings with advisor)

Skills Confidence – Time Management & Planning

Student's confidence in a variety of skills was assessed in QNR1 and QNR2. One of the key skills of interest was time management. Students were asked to identify with one of three descriptions:

- Always plan ahead
- Try to plan ahead
- Always running behind

In QNR1, 64.9% of students identified themselves in the top category (Planners), with none identifying with the bottom category of "running behind". In QNR2 the "Planners" category had dropped to 58.3% and 13.9% now identified with the "running behind" category. This suggests that some students overestimated their ability to plan, or that they experienced unexpected issues that delayed their progress.

Students were also asked to predict the time they would spend in each Teaching Period (TP) on their Projects per week (QNR1) and then to retrospectively look back on the actual time spent (QNR2). The results, shown in Figure 4, display a change in trend between the time planned and the actual time spent, with a shift towards less time spent in TP1 than planned and greater time spent in TP2 than was planned. This could possibly link to the results that showed some students actually started to run behind, based on the fact that TP2 saw a higher workload in terms of hours.

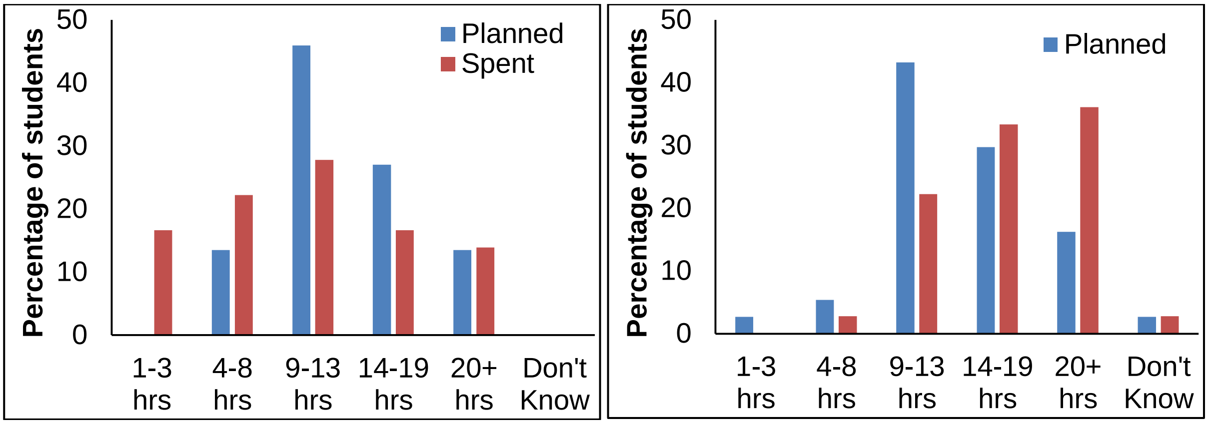

Figure 4. Time planned and spent on Projects per week in TP1 (left) and TP2 (right).

Skills Confidence – Various Skills

In QNR1 and QNR2 students were asked to rate their confidence in a variety of skill using a 5-point Likert scale ranging from 'Not Very Confident' to 'Very Confident'. The list of skills on the questionnaires was selected based on the wording of the CDIO standards, and aimed to reflect the types of skills that should be embedded throughout teaching programmes aligned to the CDIO philosophy. The students who responded with 'Confident' or 'Very Confident' were classed as confident in that skill. Between QNR1 and QNR2, there was a percentage change in confidence in some skills. Most of these were small changes, however, some did show larger changes of 9% or more, and these are highlighted in the results as shown in Table 2.

Table 2. Percentage of students identifying themselves as ‘confident’ or ‘very confident’ within list of skills provided. Any skills which showed a change of 9% or more are highlighted green (positive) and amber (negative).

SKILLS LIST	QNR1	QNR2	Difference
Problem solving	91.9	94.4	+2.6
Communication	78.4	77.8	-0.6
Apply engineering science in design-implement projects	83.8	77.8	-6.0
Teamwork	78.4	75.0	-3.4
Work to professional standards in an organisation	75.7	75.0	-0.7
Leadership	75.7	72.2	-3.5
Engineering reasoning	83.8	86.1	+2.3
Professional ethics	73.0	58.3	-14.6
Knowledge discovery	83.8	88.9	+5.1
Consider technology during product development	75.7	77.8	+2.1
Project Management	75.7	61.1	-14.6
Define customer needs	73.0	63.9	-9.1
Transform a design into a product, process, or system	73.0	77.8	+4.8
Create designs, i.e. plans, drawings, and algorithms	73.0	75.0	+2.0
Develop conceptual plans	67.6	72.2	+4.7
Critical thinking	73.0	72.2	-0.8
Self-awareness of knowledge and skills	67.6	63.9	-3.7
Consider regulations during product development	62.2	80.6	+18.4
System thinking	73.0	61.1	-11.9
Scientific thinking	70.3	83.3	+13.1
Develop technical plans	70.3	61.1	-9.2
Creative thinking	56.8	63.9	+7.1
Consider wider concepts during a project (e.g. enterprise, business and society)	32.4	50.0	+17.6
Develop business plans	27.0	36.1	+9.1
Communication in foreign languages	21.6	30.6	+8.9

Role of CDIO

Students were asked in QNR2 if they had used the CDIO process in conducting their Projects. 85.7% of students said they employed CDIO often, very often or sometimes, whilst 14.3% said they used CDIO not at all or not very often when asked the same question. In a following question that allowed open comments, students who had not used CDIO cited a number of reasons, including a purely theoretical project and not having reached the ‘Implement’ phase yet, due to the timing of their Project. In the focus groups, a consistent theme that occurred in discussions with students was that they felt the CDIO process was not applicable to Projects, and some felt that they would like to have learnt other processes for running projects and experiments.

DISCUSSION

This study was designed to allow an analysis of whether our CDIO aligned project modules in the first two years of study were equipping students with the correct skills for independent project management and delivery, through assessing their perceptions of their skills and independence during their Final Year Projects and how students transition from the group PBL modules into individual Project work.

From the results, it appears that students began their projects with high confidence levels and the feeling of independent responsibility for their work. The majority of students considered themselves good planners and had an expected level of engagement hours with the Project, which was relatively evenly split across the two TPs. Following the Project, students cited a high importance of the project advisor, which was somewhat at odds with their earlier projection of independence. This may indicate a reliance on a team of people with which to discuss ideas, designs, results and plans etc. The earlier modules may give students confidence in their abilities to manage and deliver a project, but that confidence could be partially due to the safety of a team environment. Focus groups did discuss the step from group to individual projects as being difficult. Another explanation is that the Project is a major assessment point of work, which is worth a large percentage of a student's FY, and, therefore, overall degree classification. It could be argued that the importance of the advisor is in providing feedback and validation to the student throughout the Project, particularly in terms of the quality of their work and the likely outcome of the Project. This does fit with anecdotal evidence from project advisors whose students often ask them what grade they think they are heading for at various times throughout the Project.

The majority of students considered themselves as good planners prior to the Project. However, the data showing the change in both the identification with the type of planner they were and the shift in time planned vs. time spent on their projects, would suggest that time management was an issue. In the earlier PBL modules groups are given interim deadlines, or gateways, in which they must show evidence of appropriate progress in the given module prior to the end assessment date. In the Final year Project, there is a short planning viva in week 6, but then no further assessment until the end of TP2 in around week 24. The ability to self-impose deadlines could be lacking and therefore be a reason why students were not able to do achieve an even split of workload in their Projects.

The skills that students most readily identified themselves as confident in were skills that module tutors stress the importance of to students in the earlier project modules i.e. knowledge discovery, problem solving and team work. The skills which were taught in the modules, but were not necessarily highlighted or discussed, but more embedded in the module were those that students did not identify confidence in, such as creative thinking and considering the wider concepts of a project such as business and society. Students in the focus groups discussed the CDIO process as not always being applicable, though when questioned on this, they could only relate it to group based design projects, and did not believe that it could be used in more scientific based projects. The step up between team projects and individual projects and the associated changes should not be overlooked. This was particularly highlighted by the higher dependence of advisors in the QNR2 outcomes.

CONCLUSIONS & FURTHER WORK

The aim of this work was to ascertain the effectiveness of our PBL modules in preparing students for independent work. The results show that students are confident in a range of skills, that they perceive themselves as responsible for their work, but that they place high importance on the input and guidance of an advisor. Though they did not plan as well as they expected to, and workload was not as evenly distributed across the project as they had planned, they did remain generally confident in their ability as 'good planners'. Their skills confidence increased and decreased across the range of skills, perhaps showing the importance of the individual Project in exposing students to a different type of project and learning experience.

Overall, we believe that our PBL modules do provide a high level of skills and attitudes suitable for independent project work. However, these could be improved to further develop the skills of independent learning and time management, particularly with planning and executing projects without the support of a team, and those that may seem different to projects previously tackled i.e. the ability to transfer skills across to different settings.

The limitations of this study include the non-paired nature of the data (i.e. only 13 of the 36 students completed both questionnaires), and the small size of the focus groups (7 students), which limits the ability to draw conclusive outcomes that are representative. Also, this study looks at only one cohort of students. In addition, students' perception of their skills and their competence in those skills may not be accurate, and are subjective.

Further work will involve comparing students predicted grades and skills confidence with both the grade achieved and the competence that the project advisor suggests for that individual student. Data will be gathered for the next three years in order to capture a larger cohort size and to identify any cohort-specific results. We also wish to expand the data into our Design department, to analyse the difference between students on different programmes.

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BIOGRAPHICAL INFORMATION

Laura J Leslie, Ph. D. is a Senior Lecturer and Deputy Head of Mechanical Engineering and Design at Aston University. Her research fields are in learning and teaching, as well as Biomedical Engineering and Materials. She has a particular interest in CDIO, active learning, teaching large cohorts and student centred learning.

Paul C Gorman is a Student Experience Manager at Aston University and oversees the evaluation of learning and teaching modules, as well as student satisfaction, across all Schools of study. His current PhD research project is centred around the marketisation of Higher Education in England. He has presented at numerous international Higher Education conferences over the last ten years.

Sarah Junaid Ph. D. is a lecturer in Mechanical Engineering and Design at Aston University, UK. Her pedagogical research interests include student learning, engineering ethics and professional skills development. She is a member of the Biomedical Engineering research group with an interest in biomechanical testing and computational modelling within orthopaedics.

Corresponding author

Dr. Laura J Leslie
Mechanical Engineering and Design
Aston University
Birmingham. B4 7ET.
+0044 121 204 3747
l.j.leslie@Aston.ac.uk

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IMPLEMENTING A COLLABORATIVE ICT WORKSHOP BETWEEN TWO UNIVERSITIES IN JAPAN AND THAILAND

Yuichi Anada[1], Naohiko Hayata[3], Simon Thollar[2], Mitsutaka Yasuda[3], Eiji Shimada[3], Joel Rian[1], Kenji Saito[2], Mitsuyoshi Nagao[2], Tsukasa Hokimoto[3]

Hokkaido Information University, Japan

[1] Department of Business and Information Systems
[2] Department of Systems and Informatics
[3] Department of Information Media

Natha Kuptasthien[4], Uravis Tankijviwat[5], Deachrut Jaithavil[6], Waiyawut Wuthiasthasarn[7], Pongpon Nilapreuk[8]

Rajamangala University of Technology Thanyaburi, Thailand

[4] Department of Industrial Engineering
[5] Department of Digital Printing and Packaging Technology
[6] Department of Computer Engineering
[7] Department of Photography and Cinematography Technology
[8] Department of Computer Science

ABSTRACT

Hokkaido Information University (HIU), Japan, and Rajamangala University of Technology Thanyaburi (RMUTT), Thailand, have jointly conceived, designed and implemented a short-term exchange program for students from both institutions since 2011. Its goal is to provide students with hands-on experience working together with international partners in an Information and Communication Technology (ICT) task-based setting, and to foster an abiding global-mindedness in the participants. The program is comprised of four stages: (1) Selection, (2) Competition, (3) Collaboration, and (4) Sharing. Students taking part in the international program are selected through contests at each university that involve making ICT-based works: websites, short films and programming applications. Applicants at each university are evaluated based on the projects they complete. Those chosen at each university go on to participate in two consecutive international 8-day workshops, one held at HIU and the other at RMUTT. Teams with equal numbers of Thai and Japanese students are formed, and they work together on creating collaborative web sites, short films and computer applications. After the program, they share what they have produced and learned with their peers and instructors at each university. The program aims to develop four things in the students: ICT skills, English ability, intercultural understanding, and international friendship. The teams' projects are assessed by teachers at each university using a common rubric. By taking part in the program, students acquire personal and interpersonal skills, in addition to product, process, and system-building skills. Teachers, as well as students, are an active

part of the teamwork process. As an ICT-related project-based activity that takes place internationally with English as both a second and common language, the program provides a good example of applying CDIO standards outside of an engineering context.

KEYWORDS

PBL, ICT, international collaboration, interpersonal skills, CDIO standard: 5, 8

INTRODUCTION

In this age of Information and Communication Technology (ICT), it is easy to obtain massive amounts of information from anywhere in the world. People, things and money cross the borders of countries easily, and engineers who are actively involved in their communities need to adopt global communication skills, an attitude of cooperation, the ability to act, and a sense of responsibility. By having such skills, they are able to cooperate with business partners from around the world. Developing students with these global skills is a challenge that many universities and educational institutions around the world face and embrace.

Student mobility in Europe started as the European Region Action Scheme for the Mobility of University Students (ERASMUS) program. Credit transfer is guaranteed under the provision of ECTS (European Commission, 2018) in this program. Even in ASEAN countries, student mobility has been realized under the provision of ACTS (ASEAN University Network, 2009). Taking this fact into consideration, it has been proposed that “Internationalization & mobility” should be added as an optional CDIO standards (Malmqvist, Edström & Hugo, 2017).

Hokkaido Information University (HIU) in Japan and Rajamangala University of Technology Thanyaburi (RMUTT) in Thailand have jointly conceived, designed and implemented an ICT-based exchange program for students from both institutions. The program has run annually since 2011. Its primary purpose is to foster global-mindedness and intercultural appreciation that students will take with them after graduation. International collaboration and globalization are playing more significant roles in various aspects of society and real-world systems. This program focuses especially on the flow of student mobility.

The program is comprised of four separate but interrelated stages: (1) Selection of students, (2) Competition between students, (3) Collaboration among students, and (4) Sharing by students. During the Collaboration stage, the most intense part of the program, students work in teams to conceive an ICT project; a web site, a short film, or a computer program. They continue by designing and implementing accordingly to achieve their goal. It should be noted that during the workshop phase, all students communicate in English, a second language for all of them. In taking part in the project, students need to acquire personal and interpersonal skills, in addition to product, process, and system-building skills. Furthermore, it is hoped that such skills will not only be embraced by students but also faculty at each institution. This paper presents an overview of the program and how it connects with CDIO standards.

INTERNATIONAL COLLABORATION

The program between HIU and RMUTT is titled International Collaboration. Throughout the stages of the program—Selection, Competition, Collaboration and Sharing—there are four aims, namely, that students will develop:

1. ICT-based skills
2. English ability and confidence
3. Intercultural understanding
4. International friendship

To achieve these aims, the International Collaboration program follows the original iWDC model. iWDC stands for international WEB Design Contest, and this competition was the core component of the collaborative program, with the international Short Film Contest (iSFC) and international Computer Programming Contest (iCPC) being added several years after its inception in 2011. The complete iWDC model is expressed graphically in Figure 1. From the Selection stage to the Sharing stage, the program extends over one year, with more than twenty faculty and auxiliary members from each university taking part in the project as advisors, facilitators or managers. Despite the long lead-up time, work tends to be concentrated into just a few days in the Selection, Competition and Sharing stages, with the Collaboration stage being the most demanding, resulting in a busy non-stop month for all involved, as can be seen below.

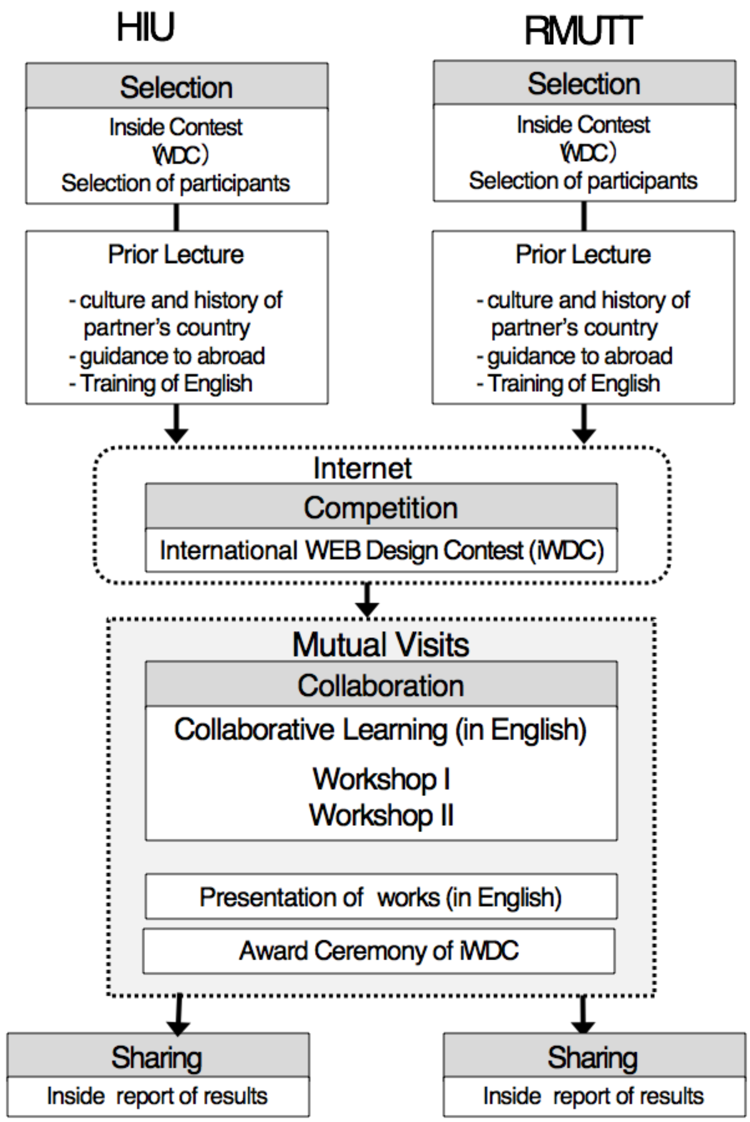

Figure 1. iWDC model

Stage 1: Selection of Participants

ICT-based project contests (Web Design, Short Film, Programming Applications) are held internally at each of the two universities. In the initial Selection stage, the aim is to select 18 students from each university and offer them the opportunity to take part in the international collaborative program. Works to determine selection are completed by interested students in their native language outside regular lecture hours, with contest entries open from January to early May. Committees from each university evaluate applicants' finished works in order to select candidates for the international program. Students given the chance to take part in the workshop must meet two criteria; superior scores in the internal contests, and a grade point average (GPA) of 3.0 or more. The award ceremony for the 2017 ICT Contest at HIU was held in June (Figure 2a). Projects covered a broad range of topics, including such themes as "Sapporo Mystery Map" and "The Perfect Combination of Thai Food" in the iWDC (website category), “Lost page” and “Riddle Room” in the iSFC (short film category), and a “Role Playing Game” and “Gas Detection System” in the iCPC (computer programming category).

Students who meet the criteria and are accepted in the program must attend seven pre-program classes in June and July prior to the beginning of the collaborative workshops. These classes help prepare students for their international experience, and include background lectures on Japanese and Thai culture, guidance for travelling abroad—a first-time experience for many of the student participants—and practice with communicating and giving presentations in English. During these pre-program classes, students convert their projects from their native language to English in preparation for the next stage of the program, the Competition stage. It is during this stage that English as a lingua franca becomes apparent to students (Rian 2014). Figure 2b shows a pre-program class in 2017 at HIU. During the Selection stage, the initial aim is developing ICT-based skills.

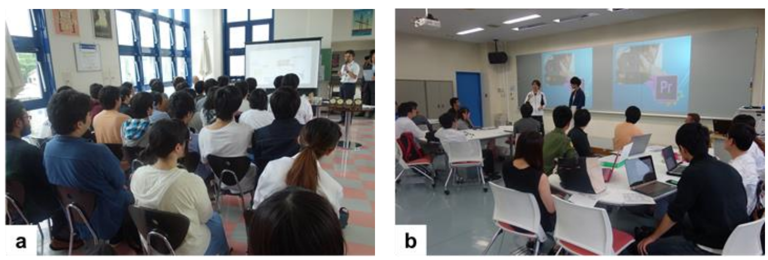

Figure 2. (a): 2017 HIU Award Ceremony, ICT Contests, June 2017 at HIU.
2(b): Pre-program class at HIU, July 2017.

Stage 2: Competition Between Students

The Competition stage, indicated in Figure 1, aims to develop ICT skills between the two universities in order to enhance students’ ICT ability. As mentioned above, all student work must be translated into English. Evaluation is made by faculty members from each university who are involved with the International Collaboration program. The winners of the contests receive awards on the final day of the workshops. The presidents of both universities award trophies and certificates. During the Competition stage, students develop 1. ICT-based skills and 2. English ability and confidence.

Figure 3. Award Ceremony 2017 at HIU.

Stage 3: Collaboration Among Students

The Collaboration stage is the core stage of the program. Unlike the Competition stage, prizes and rankings are not awarded. It consists of two workshops, one held at HIU, one at RMUTT outside regular lecture hours. Students collaborate to produce ICT-related work, and work with each other over two consecutive 8-day programs, held at the respective institutions. Both the order and date of the workshops change annually, according to university needs. For the past several years, the program has accommodated equal numbers of students from each university: 18 from HIU and 18 from RMUTT. Although increasing the number of participants has been considered, 18 students from each institution is an appropriate number given necessary resource demands in terms of accommodation, support faculty and cost. While other institutions have expressed an interest in participating, increasing the scale and size of the program would currently be difficult, for the reasons previously noted.

To enable collaborative team selection, teams initially formed at each university before the workshop introduce their respective projects to one another. Based on the presentation and degree of interest, new collaborative teams are formed with members from each university. Just as the visiting order changes annually, which university students create and propose topics, and which select the team they want to join, also alternate on a yearly basis. Teachers from both universities facilitate the team formation process.

Before and after the team formation, an “ice-breaking” (meet-and-greet) session and a short lecture with program overview are given to students. The ice-breaking session is not only a chance for students to meet and become familiar with each other but also a chance to practice English communication. In the program overview, students learn about time management, and how to systematically and efficiently design and complete their projects within the time restraints. After the first 8-day workshop (Workshop I), all students move to the other university for the second workshop (Workshop II). Figure 4 shows team formation, the ice-breaking session and the program overview at RMUTT in 2017.

Figure 4. (a): meeting students, (b): team formation, (c): program overview at RMUTT (2017).

Although students are challenged by having to communicate in English during the first few days, they tend to adapt quickly. Teachers are available to help translate, but in most cases students manage to communicate on their own. A few days into the program, all teams can be seen to be working on their projects autonomously. They engage each other through their ICT skills, in addition to sharing their knowledge and cultural backgrounds. This hands-on engagement helps them develop as globally-minded people, and friendships develop between them accordingly. Figure 5a shows a snapshot of teams during Workshop I at RMUTT in 2017.

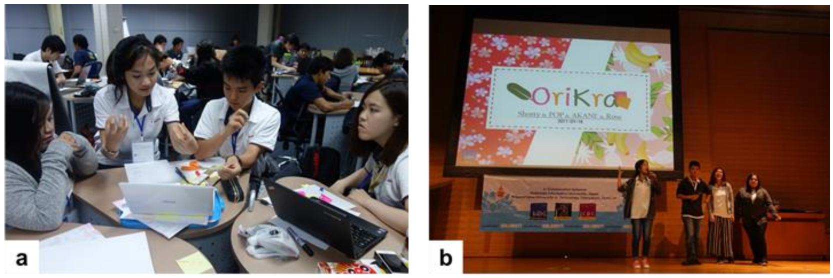

Figure 5. (a): Workshop I at RMUTT, (b): presentation of students’ work Workshop II (2017).

On the final day of Workshop II, each team presents their work in English to an audience of students and faculty from both universities (Figure 5b), in addition to the award ceremony from the Competition stage also being held. In a combined meeting of faculty from both HIU and RMUTT, a comprehensive assessment of workshop learning outcomes is made for each student. On the basis of this assessment, each institution grants 3 credits to the students based on the academic equivalence standards of each institution. During the Collaboration stage, students develop (1) ICT-based skills, (2) English ability & confidence, (3) Intercultural understanding and (4) International friendship.

Stage 4: Sharing by Students

After the Collaboration stage, team works are shared with other students and faculty through presentations and reports at each institution in their respective native languages (Thai or Japanese). Audiences include non-participating students and faculty members. The international program’s appeal and value can be conveyed to prospective future participants and faculty.

RUBRIC AS A TOOL FOR EVALUATION AND AWARENESS

The International Collaboration assessment committee began using a rubric to evaluate students’ projects on a trial basis in 2015. Seven broad criteria are currently used in the project evaluation process: First Impression, Ideas and Concepts, User Experience, Graphic Design, Technical Skills, Volume, and Content Originality, each with detailed descriptors (see Table 1). Each criteria is further divided into sub-criteria, each with their own appropriate descriptors. Further explanation appears below.

Some of the participating students are multi-skilled, having both graphic design skills and web coding skills. Other less-advanced students team up with those who are more able, and still others, who may have poor graphic skills, use copyright and/or royalty free images to improve the look of their work. Such factors are taken into account in the evaluation process, and are reflected appropriately in the criteria and descriptors. Similarly, with respect to coding and programming technology, open-source and/or free material with various functions is readily available on the internet, and mashup technology allows students to combine those technologies to create new services. Carefully designed descriptors for each category allow accurate assessments to be made when ranking projects, and the success criteria contained therein ensure appropriate evaluations for the work of students who can, for example, write original programs from scratch as compared to those who use mashup technology.

Evaluations not only reflect the level of technical skill, but also similarly indicate the degree of graphic creativity as well as originality of content, amongst other criteria. The first impression upon opening a new web page, for example, tends to be affected by numerous variables, ranging from function to layout to interface design. The quality of the user experience is governed by the degree and extent of interaction with the content being browsed. Experiences can vary greatly due to how compliant web sites are to multi-platform usage, allowing access from such devices as tablets, smartphones and PCs, while also being stable when viewed using any popular browser on a device running on one of several common operating systems. Participating students thus need to carefully conceive and design their work, and the quality of planning is an extremely important factor in evaluating and scoring the entries. In addition to the degree of originality, how well the concept of the work meets the purpose or target is also evaluated in the Ideas and Concepts criteria.

Table 1. Criteria of Rubric (without descriptors)

Criteria	Sub-criteria	Criteria & Score					
		Poor (1)	Min (2)	Fair (3)	Good (4)	Exc (5)	SUB-TOTAL (/15)
(A) *First Impression*	• *Impact/Impression*						
	• *Web Site Utility*						
	• *English Language Use*						
		Poor (1)	Min (2)	Fair (3)	Good (4)	Exc (5)	SUB-TOTAL (/10)
(B) *Idea & Concept*	• *Degree of Originality*						
	• *Clarity of Purpose*						
		Poor (1)	Min (2)	Fair (3)	Good (4)	Exc (5)	SUB-TOTAL (/15)
(C) *Volume*	• *Text Usage*						
	• *Image Use*						
	• *Size/Construction*						
		Poor (1)	Min (2)	Fair (3)	Good (4)	Exc (5)	SUB-TOTAL (/15)
(D) *Graphic Design*	• *Layout & Composition*						
	• *Expression & Appeal*						
	• *Graphic Design Skill*						
		Poor (1)	Min (2)	Fair (3)	Good (4)	Exc (5)	SUB-TOTAL (/15)
(E) *User Experience*	• *Degree of Interaction*						
	• *Multi-Platform Function*						
	• *Response*						
		Poor (1)	Min (2)	Fair (3)	Good (4)	Exc (5)	SUB-TOTAL (/20)
(F) *Technical Skill*	• *Coding*						
	• *Programming*						
	• *Browser Compatibility*						
	• *Degree of Completion*						
		Poor (1)	Min (2)	Fair (3)	Good (4)	Exc (5)	SUB-TOTAL (/10)
(G) *Own Content*	• *Web Content*						
	• *Elements - photos, widgets etc*						
							TOTAL (/100)

The assessment committee has continually discussed the validity of the results obtained using a rubric as a way to evaluate student projects. The initial version was complex, and contained more than ten detailed dimensions, making evaluation both time-consuming and difficult. After several iterations, the rubric has been revised to become a more convenient and effective evaluation scale. Making the evaluation criteria available to the participants, and explaining the rationale behind the descriptors has proved useful in helping them to understand what is important when producing ICT-based work.

STATUS OF THIS PROGRAM IN CDIO

This International Collaboration program represents an adaptation of CDIO to a context where the students receive opportunities to improve skills in diverse teamwork, communication and project management. In the workshop, students go through a "conceive – design – implement – operate" process over a 1-month long program. Personal and interpersonal skills are continually developed and honed over a series of activities. Teams are formed after students describe their previous work and their own strengths to a full audience of all participants, all undertaken in non-native English [CDIO Syllabus 3.3.1]. Faculty from both HIU and RMUTT facilitate and provide support in the team formation phase. Participants take part in short lecture and practice sessions designed to help each group systematically plan and develop the project [CDIO Syllabus 4.3.4]. In addition to developing such teamwork skills, students also experience long-distance communication and cooperative learning [CDIO Syllabus 3.1, 3.2]. Employing modern technology, such as feeds, timelines, SNSs or online translation, students can easily communicate with each other. At the end of the project, final presentations are made in English by each group to an audience of other participants and faculty, utilizing appropriate multimedia and electronic aids, highlighting newly developed skills [CDIO Syllabus 3.2.4, 3.2.5, 3.2.6, 3.3.1].

CONCLUSION

This project, which grants 3 transferable credits to all participating students, promotes internationalization and the mobility of students and faculty members between institutions, as proposed by Campbell and Beck (2010). It is also in line with additional new CDIO standards proposed by Malmqvist et al. (2017). This program exposes students and faculty members to international experiences and the relevance of mobility in collaborative education. It furthermore raises awareness of working in different cultures, and helps promote effective communication strategies and skills. Additionally, participating students are given opportunities to practice and develop their English language ability in various ways: reading, writing, speaking and presenting. Just as other projects have aimed to develop internationally-minded students (Enelund et al., 2016; Koster et al., 2013; Gourves-Hayward et al., 2013; Bergman et al., 2017), our project strives to enable similar outcomes, such as understanding cultural differences, learning how to communicate in multinational teams, and a focus on English as an international communication medium. While some aims may differ, with other projects having focused on emphasizing manufacturing skills, or collaboration with enterprises, our project is characterized by encouraging long-term independent activity of students driven by short-term concentrated active learning.
The project is one of the fruits of a complementary 10-year partnership between HIU and RMUTT.

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BIOGRAPHICAL INFORMATION

Yuichi Anada is a Professor in Department of Business and Information Systems at Hokkaido Information University, Japan. He has actively participated in HIU-RMUTT international collaboration projects as a coordinator since 2011.

Natha Kuptasthien is currently assistant to president for International Relations and an associate professor in the Industrial Engineering Department, Faculty of Engineering, RMUTT. She has actively participated in HIU-RMUTT international collaboration projects since 2011.

Naohiko Hayata *Ph.D.* is currently a Professor at the Department of Information Media, Hokkaido Information University, Japan. He is an original member of HIU-RMUTT international collaboration projects. His academic field is Environment-Behavior Studies.

Simon Thollar is a Professor in the Faculty of Business Administration & Information Science at Hokkaido Information University and an original HIU-RMUTT project member . His research interests include e-learning, active learning, student & teacher motivation, and engagement.

Mitsutaka Yasuda is a professor in Department of Information Media and Director of the Media Creative Center (MCC) at Hokkaido Information University. His current research is pedagogy for practical education in digital content and design industries.

Eiji Shimada is an Associate Professor in the Faculty of Information Media at Hokkaido Information University, Ebetsu, Japan. His current research focuses on Filmmaking, Film education, and International Co-production to foster global persons.

Joel Rian is a full-time lecturer in the Faculty of Business Administration & Information Science at Hokkaido Information University. Currently a PhD candidate through Macquarie University in Sydney, he is researching communication strategy training and use in the EFL classroom.

Kenji Saito is an Associate Professor in Faculty of Information Media of Hokkaido Information University, Ebetsu, Japan. His current research focuses on artificial intelligence.

Mitsuyoshi Nagao is a Professor in Department of Systems and Informatics at Hokkaido Information University, Ebetsu, Japan. His current research focuses on Tourism Informatics, Complex Systems and System Engineering.

Tsukasa Hokimoto is an Associate Professor in the Faculty of Information Media at Hokkaido Information University. His research interests include statistical modeling for data analysis and its application in analyzing natural phenomena related to oceanography and meteorology.

Uravis Tankijviwat is a deputy Dean for Academic and Research Affairs in the Faculty of Mass Communication Technology, RMUTT. He promoted CDIO implementation to undergraduate programs for enhancing the graduates in the field of mass media.

Deachrut Jaithavil is a lecturer at the Department of Computer Engineering, Faculty of Engineering, RMUTT. He has actively participated in HIU-RMUTT international collaboration since 2011, responsible for the international Web Design Contest.

Waiyawut Wuthiasthasarn is an assistant professor in the Department of Photography and Cinematography Technology in the Faculty of Mass Communication Technology, RMUTT. He is involved in international Short Film Contest for HIU-RMUTT international collaboration.

Pongpon Nilapreuk is a lecturer at the Department of Computer Science, Faculty of Science and Technology, RMUTT. He has actively participated in HIU-RMUTT international collaboration since 2012, responsible for international Computer Programming Contest.

Corresponding Author

Professor Yuichi Anada
Hokkaido Information University
59-2 Nishi-nopporo
Ebetsu, Hokkaido, JAPAN 069-8585
81-11-385-4411
anada@do-johodai.ac.jp

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A FRAMEWORK FOR SECOND LANGUAGE, COMMUNICATION AND ENGINEERING LEARNING OUTCOMES

Avinda Weerakoon, Nathan Dunbar

College of Engineering, Construction and Living Sciences, Otago Polytechnic

ABSTRACT

Teaching and learning of engineering courses and programmes in a second language (L2) or for non-native speakers (NNS) has become increasingly common in recent years as international connections between institutions grow, industries globalise, and markets and the workforce become more fluid. The role that a L2 plays in engineering education varies depending on context, but there is no doubt that L2 and NNS involvement add an additional level of complexity to the teaching and learning environment. Study abroad students are tasked with developing technical engineering, communication and language skills simultaneously. Research suggests that providing additional instruction in the L2 aimed at the *specific* needs of a course, programme, or professional trade is beneficial. However, this instruction has seldom been taught in tandem with, much less integrated into a project-based engineering programme that focuses on both oral and written communication skills. To integrate second language, communication and engineering content outcomes into a project, we need to develop assessments that meet multiple learning outcomes across these areas, and to monitor the degree to which L2 impacts on the ability of NNS to perform engineering and communication outcomes. In this paper, we report on how a L2 (in our case English) is being integrated into projects, and how communication and language progress and learning outcomes can be assessed within the engineering project framework. Ultimately, we attempt to provide a new project framework that can help coordinate the engineering, communication and language learning outcomes with engineering graduate attributes in a project-based, study abroad programme.

KEYWORDS

Second language learning outcomes; Communication and teamwork skills; Project-based Learning; Integrated project framework for Language, Communication and Engineering Content; CDIO Standards 1,2,3,5,7,8,11

INTRODUCTION

One of the essential features of a CDIO approach to engineering education includes embedding interpersonal and communication skills into a program. Communication skills are important for any discipline, and engineers must be able to communicate technical information accurately and clearly to both technical experts and non-technicians alike.

Engineering requires working in teams, as well as communicating through written reports, presentations and correspondence, and involves the use of language, visual and numerical information. These skills and attributes which the engineering students must acquire at the completion of an engineering program are described within the CDIO syllabus, and, along with a solid foundation in engineering principles, are believed to be the essential tools needed to handle the demands and the challenges of a dynamic world (Armstrong 2008).

As engineering courses and jobs have become more globalised, there has been more focus on how to help non-native speakers acquire the language skills needed for engineering communication. CDIO is an international initiative, and the CDIO syllabus 2.0 includes an item recognising the potential importance of second language learning within the CDIO framework. There is little detail, however, on how second language learning could or should be integrated with other aspects of the CDIO initiative, nor how second language learning outcomes or attributes can be incorporated into, or affect the outcomes of, project-based learning. In this paper, we explore how both second language and interpersonal skills can interact with engineering knowledge and technical skills in a project-based curriculum.

Course Structure

The Otago Polytechnic (OP) and Kanazawa Technical College (KTC) joint program (CEE) lasts for 32 full teaching weeks. The students in the program study Mechanical, Electrical and Information Technology (IT) courses. Weerakoon, Dunbar & Findlay (2014) and Weerakoon and Dunbar (2017) describe in detail the development and content of projects for the Mechanical Engineering course, which constitutes about 10% of the study load. English language skills account for about 50% of the program credit.

Engineering English

While the CDIO syllabus describes language features in general, there is little detail on the nature of engineering genre, and how genre can aid students in achieving successful communication goals. The best-known approach to analysis and teaching of professional and academic discourse is Swale's (1990) exploration of genre and move structures of a text. While significant research has been carried out on aspects of engineering English including technical vocabulary (Mudraya, 2006; Ward, 1999), grammar (Conrad 2017), and rhetoric (e.g. Artemeva, 2005; Flowerdew, 2000; Parkinson, 2017), these studies focus on how language classes can help students do better in their content classes, rather than using the language in the content class as an integrated component of the course.

Initiating students into the engineering genre is one goal of engineering courses. Flowerdew (2000) examined the genre and move structure of final-year engineering project reports. Dannels (2009) found that key factors differentiating successful engineering design presentations were the use of explanatory rhetoric to justify designs, creating a proximity to the audience, use of oral fluency, adoption of a professional language approach, and the use of cohesive devises to link ideas, sections, designs and solutions together.

Common moves that have been identified in engineering reports and presentations include: establishing relevance of topic; listing materials; describing procedures; describing a design; justifying a design decision; identifying a problem; evaluating a design solution; announcing results; interpreting results.

In recent research, some attempt has been made to more closely connect language and engineering content teaching. Tatzl et.al (2012) describe the development of a project-based technical writing model, which aims to integrate the teaching of report writing with a first-year engineering project. They argue that shared assignments in content and language classes raise the relevance for students. They conclude that collaboration between content and ESP instructors increases task authenticity, relevance and significance for students, and that student motivation can be fostered by integrating the project process into both language and content courses. Nekrasova-Beker and Beker (2017) describe the integration of project-based learning into language instruction in a foundation course at university. Rather than focusing only on report writing, this study assesses language through presentations and final reports. This "project" was not a technical engineering project, however, but rather preparation for an "engineering job interview".

INTEGRATION OF ENGLISH INTO ENGINEERING PBL

Learning outcomes for language courses generally involve some iteration of the following (based on NZCEL Level 4/5; equivalent to CEFR mid-upper B2 range). The learner

- understands the main ideas of complex speech (of professional relevance)
- is adapted to style and register
- is adapted to context, audience and purpose
- has a good range of lower frequency vocabulary relevant to topic
- writes well-constructed sentences including complex structure
- can express ideas orally in a spontaneous and fluent manner

In our course developed for an engineering context, these outcomes are realised as follows:

- Identify and accurately describe an engineering "problem"
- Describe engineering designs using accurate and precise terms
- Explain and justify engineering design / modelling decisions
- Identify and be able to use the problem-solution pattern common to engineering communication
- Identify and use cohesive devices to link parts of reports and presentations together
- Demonstrate an awareness of audience and the importance of tailoring communication to the level and interest of the audience
- Demonstrate techniques for developing and maintaining team / group relations

We believe these learning outcomes can be integrated and demonstrated within a project framework, especially one that involves the completion of a project report and presentation.

Based on our understanding of engineering genre and communication described above, we have developed an approach where some language skills are built directly into the project curriculum, while other aspects that require a more linguistic approach are taught in supplementary tutorials. We adopt the approach that technical vocabulary is best taught through the content matter in context, but we use language tutorials to further explore the language of measurement and accuracy of expression. This is to help students avoid the trap of using imprecise terms such as 'a lot', 'a few' etc. which are often inappropriate in an engineering context (Conrad, 2017).

Oral fluency depends on coordination of several skills including pronunciation, intonation, vocabulary and spoken grammar. While we have tutorials to deal with pronunciation and intonation, the project group work provides the ideal context for the practice and development of oral fluency skills, in a less threatening environment than a formal presentation, which we reserve for later in the course.

We teach engineering genre as an integrated part of project work, through the use of a progress "workbook", final project reports and final project group presentation. This provides an authentic task that students become engaged in and can be given formative feedback on as the course progresses. Finally, we provide students with a discussion on the importance of understanding and tailoring a report or presentation to the audience.

Table 1. The course timeline for both language and engineering content knowledge

Week	Engineering Tasks	Language-focused tasks
1-5	Analyse theory and principle of forces in mechanics	Technical accuracy
5	Test 1 weighting 10%	
6-7	Project 1: Team building weighting 10%	Oral fluency Identify and describe a problem
8-11	Analyse forces and motion, work energy and friction	Oral / written explanatory rhetoric
11	Test 2 weighting 10%	
12-14	Project 2: Multidisciplinary weighting 20%	Engineering report - structure
15-16	Sustainability, energy resources and resource management	technical language
16-32	Project 3 Main project weighting 50%	Engineering genre – report and presentation Audience

TEAMWORK AND COMMUNICATION SKILLS

Language skills provide the fundamental foundation that students need to be able to communicate effectively on engineering tasks and support broader communication skills in a project-based learning environment. The CDIO initiative encourages the use of groupwork and communication skills, and PBL provides the ideal environment to integrate language, teamwork and content-based skills. However, PBL also brings considerable potential for interpersonal conflicts and unequal distribution of the workload amongst team members during the project cycle. We have found that the success of PBL depends on the flexibility and adaptability to challenging conditions during the CDIO process, and that, in addition to development of language and negotiation skills, early awareness of the diversity of student capability is essential in forming effective teams for PBL.

Team formation

Prior to the first project groupwork, we provide engineering content sessions that give students the foundation theory and the principle of forces in mechanics, the correct use of analysing forces in mechanical systems and their relationships to engineering applications. This engineering knowledge is sufficiently addressed to provide an insight into the basic underlying physics needed to develop a systematic approach to solving a small engineering problem.

Observations of English oral fluency, the general character and attitude of the learners during these early weeks, as well as the assessment of the first engineering test provide the basis for determining team leaders. We identify students who are disciplined, motivated and ready to solve problems in a self-directed way. This analysis is important to ensure all teams consist of even strength, especially in situations where the resilience of the team harmony and coherent decision-making process are tested as teams encounter design or implementation problems.

Each team consists of at least four members. Because of the multi-disciplinary background of the learners, we ensure that mechanical stream students are distributed evenly. As far as possible, we also attempt to achieve a gender balance. To achieve this, the engineering and English language instructors consult to choose team leaders, and these team leaders then pick the composition of the teams. We have found this model to work well with our Japanese students, as it helps to reduce interpersonal conflicts while maintaining team diversity. In cases where conflicts with team composition do occur, they are monitored during the initial project by the instructors and team adjustments can be made for subsequent projects.

Language and Communication skills development

Skills gained through group project work include an insight into group dynamics, collective decision making and exposure to viewpoints of others. Learners are also learning to solve a technical problem in an unfamiliar environment and apply theory into a working example. These attributes are used for formative assessment in the preliminary project, which helps to build on initial engineering language knowledge and oral fluency and familiarises learners with interpersonal communication skills.

After the completion of the first project, which consists only 10% of the overall weighting, a reflective session asks the learners to discuss team processes, and composition.

The second project provides learners greater freedom in decision making to arrive at a novel solution, as the solution to the technical problem increases in complexity and the project is open-ended. This project is also multi-disciplinary, so there is a greater level of knowledge transfer from other disciplines. Learners need to combine skills from two engineering disciplines synchronously to achieve a successful outcome. Consequently, there is a greater potential for interpersonal conflict amongst team members. Although interpersonal conflicts are often looked upon negatively in PBL, these projects are a good springboard to examine how learners navigate through the complex layers of language and interpersonal skills when they encounter conflicts of interest. This is quite common when teams find that their original design does not deliver the desired results. This model of learning through doing helps learners reinforce their engineering knowledge, but also gain essential oral language skills and communication attributes without having to provide separate lessons on teamwork theory.

ASSESSMENT

While integration of language and communication skills into PBL has been shown to be both possible and potentially effective, it is important that we build into our projects a system of assessment that both accurately and fairly represents the diverse learning outcomes, as well as meets the requirements of evidence of learning for any course moderation or audit.
The mechanical engineering course consists of three projects, and the project outcomes, complexity and the weighting are raised systematically as language fluency and accuracy improve and the students adapt to working within a PBL environment.

The project workbook

At the outset, students are encouraged to record evidence of their complete design lifecycle in a workbook or portfolio. These workbooks are both a record, and a resource for helping learners develop their technical language skills. Quite often in the initial stages, learners fail to demonstrate good record keeping practice and they are vague in describing their design decisions. Where learners simply record a design graphically, they can be prompted to add a brief description in words, and then to list advantages and drawbacks of their design. They may be prompted to calculate the forces and estimate number and size of screws needed, or precise measurements required. This also serves to introduce learners to the use of more technical terms used in designs. If these deficiencies are addressed regularly in the primary project, they are less likely to be repeated in the final project. Since Project 1 only accounts for 10%, the project provides the basis to develop this good practice.

In the second project, the members need to exercise a greater level of coordination, resilience, and more fluent communication skills to execute and complete all the project outcomes. This project has no clear formulae for a successful design, nor a calculation model for achieving the project outcomes. At this stage, learners need to ensure that the workbook is updated with all the evidence of design selections, and the design errors and weak decisions are not repeated. Earlier work on accurate description of designs and listing advantages and disadvantages can now be developed so that learners more explicitly justify their design selection using the evidence recorded in the workbook. This also offers an opportunity to examine the precise wording used, so that learners develop the habit of using expressions such as “the *preferred* option for…is…because…” (see Conrad, 2017).

Further, at this stage the evidence in the workbook should show the contribution from each member of the team and their involvement and task assignment. Growing oral fluency can be monitored by joining group discussions and ensuring design selections are based on collective group negotiations rather than the personal work of one member. The evidence recorded in the workbook is the basis to establish the contribution to design lifecycle from individual members. The workbook also reduces burden on both the facilitators and the students from having to conduct various forms of individual assessments to determine their contribution to the total project.

Final project report and presentation

The main project is multi-disciplinary and offers integration across other disciplines including CAD and Electrical Engineering. This project also allows the students a considerable length of time to identify and assess the problem, transfer knowledge from other disciplines and advance deep thinking for creative problem solving. Students now have both the technical, communication and language skills to work on a fuller project report and presentation. At this stage, the workbook provides a record that can be formed into a full report using guidance from engineering genre studies. Students can be familiarised with the moves associated with each section of a report, including moves that have not been covered in earlier projects such as establishing relevance of a topic, and following a sequence of problem-solution patterns of rhetoric. Finally, the testing of the project final product is conducted well before the submission of the final report. This enables the teams and individual learners time to reflect on the test outcomes and include an evaluation of their own design solutions and comparison of the effectiveness of their designs compared to other teams, and to include those conclusions in the final report along with the recommendations and/or suggested improvements.

The final report and presentation are summative assessments for both the mechanical engineering course and the English language course. The Engineering English learning outcomes can all be assessed through the report and presentation, which can provide adequate evidence for moderation.

ANALYSIS

Team Diversity and Performance

The largest proportion of students in our program come from an IT stream and, as a result, there is a diversity of student motivation towards mechanical engineering study. Figure 1 shows the result distribution for individual test component (20%) and team project 3 (50%). The graphs indicate that learners who perform well in individual assessments also do well in PBL. One surprising result from our case study is that highly motivated IT students can achieve high accomplishments in PBL in terms of innovation, novelty and success, despite no prior exposure to the mechanical engineering discipline. This may show that the multi-disciplinary nature of the projects can facilitate knowledge and skill transfer from other disciplines.

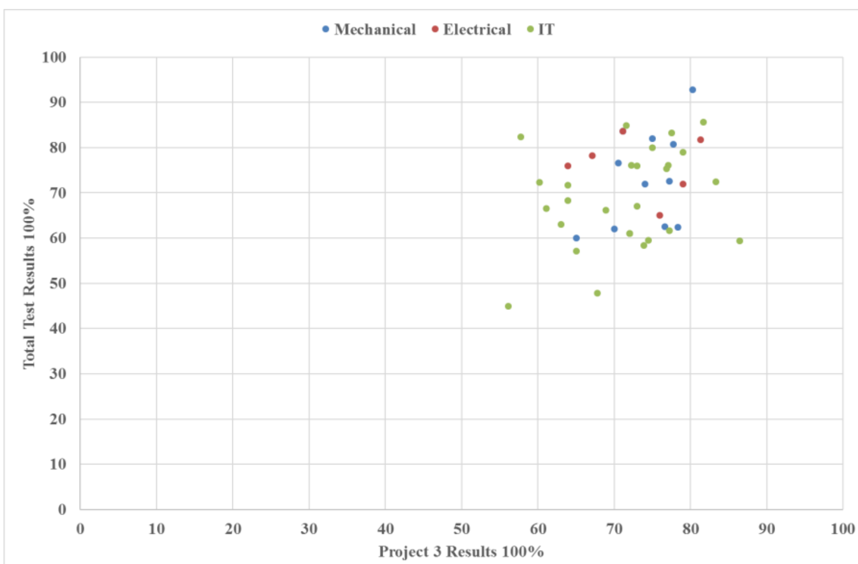


Figure 1. Tests vs Teamwork (Project 3)

Figure 1 also shows that learners who produce only poor to average scores in individual assessments can be motivated to perform well in PBL. In our experience, this relies on team composition, and is generally accomplished through combined effort of task allocation based on individual strengths and through peer support. Learners in the mid-range (between 60-75%) in individual assessments accomplished similar results with PBL.

English language results plotted against project scores (figure 2) also show similar trends. English language skills have also been measured through external TOEIC examinations after the completion of this programme. When these results are compared with indicative results from English tests before the programme, they show significant growth of 200-400 points, which would indicate that Engineering English and PBL provides a basis for growth in general English communicative ability as well. We are aware that the TOEIC test is not an ideal test for engineering English, nor does it necessarily reflect actual communicative ability. We would argue that it is likely our learners in fact improve more than is indicated by this test in terms of communicative ability due to the interactive group work they are involved in.

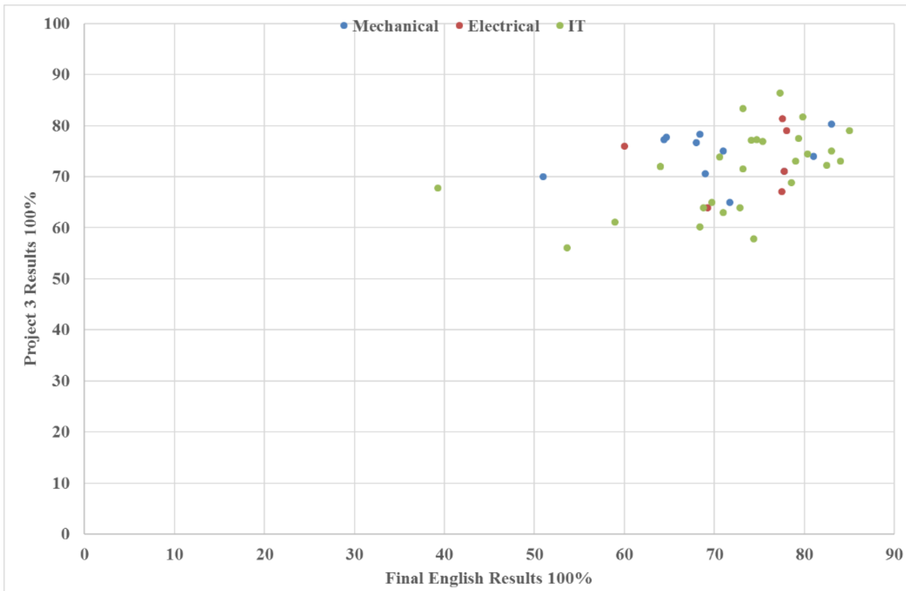


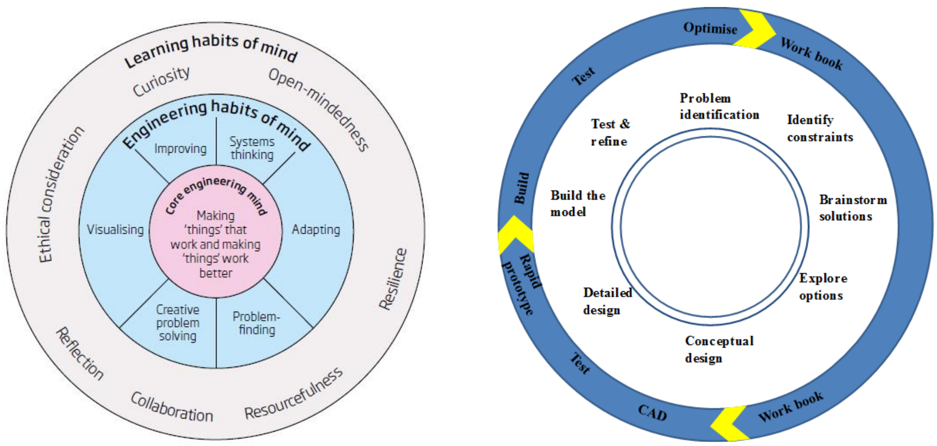
Figure 2: English final marks vs Project marks

Qualitative Feedback

With our most recent cohort we carried out a qualitative feedback analysis based on an initial questionnaire survey (n=15) and more in-depth follow-up interviews. The results suggests that about 80% of our learners agree that engineering project reports and presentations are useful, and 73% expect to use what they have learned from these courses in their future job. Most students (87%) enjoyed working in a team. Several also commented on the importance of teamwork to successful project-based learning, and one suggested more training in developing and maintaining team relations. This is a factor also noted by Neal, Ho, Fimbres-Weihs, Hussain, & Cinar (2011) in their feedback survey. 73% felt that writing reports and giving presentations in English was a difficult task, and 60% agreed that combining English with engineering projects helped them to understand the engineering concepts. Two learners commented that they had never written a comparable report in their L1, and that they needed more guidance in "how to write" and "what to write about". One learner wrote that he or she didn't "have words enough for writing".

DISCUSSION & CONCLUSION

Lucas & Hanson (2014) argue that engineers think and act in a certain way (shown in figure 3a) and this is backed up by linguistic research into engineering genre (Parkinson, 2017). The model that we follow for the complete design lifecycle is shown in Figure 3b, and emphasizes the importance of evidence gathering and problem refinement. The thinking process for the design problem through the CDIO process is recorded in the workbook that each team maintains. The evaluation of team assessment for individual members is conducted using the information provided in the workbook. The workbook is expected to contain the aspects of engineering mind as established by Lucas & Hanson (2014).



a) Engineering mind b) Lifecycle of a product design

Figure 3 Engineering habits of mind (Lucas & Hanson, 2014) and Lifecycle of a product design *(Weerakoon, Dunbar, & Findlay, 2014)*

The intention of the engineering course is to primarily focus toward harnessing these characteristics, but these skills clearly depend on other essential skills and attributes, including communication and language skills. An integrated approach to teaching language, communication and engineering problem-solving skills through PBL as described in this paper can support the development of the engineering habits of mind.

The following diagram, based on a generic PBL model described in Beckett & Slater (2005) is a tentative effort to make these connections explicit.

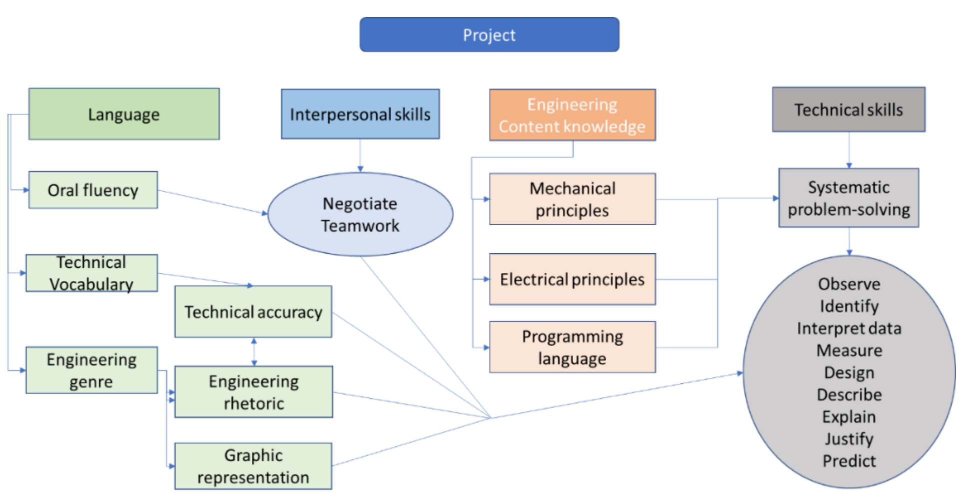


Figure 4. Framework for integration of Language, Interpersonal Skills and Content Knowledge for Engineering

Beckett and Slater (2005) call for the making of learning objectives of PBL activity transparent to the students to avoid differences in beliefs that may cause conflicts. The primary purpose of this diagram is to show students the connections between language, communication skills and content learning.

Our recommendations for the integration of L2 into a PBL course or program are necessarily tentative, but we believe using a workbook or similar approach to record team discussions, decisions and evidence of team progress can help initiate students into practices of the engineering mind and engineering language genre simultaneously, and that this process helps establish connections between content and communication skills. We believe that this approach is both practical and effective, and that the framework presented above can help make that those connections more explicit for students. We acknowledge that much further research needs to be done to show correlation between improvements in Engineering language skills, oral fluency, project work and engineering knowledge. We also need better measures of learner awareness of engineering genre prior to their study on our programme. The diagnostic test being developed by Fox & Artemova (2017) offers scope for improved measurements.

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BIOGRAPHICAL INFORMATION

Avinda Weerakoon Ph. D. is a Senior Lecturer in Mechanical Engineering at Otago Polytechnic, specializing in advanced thermodynamics, energy engineering and sustainable building construction practices.

Nathan Dunbar is a senior lecturer and academic programme coordinator for the Certificate in English and Engineering. He has a background in applied linguistics, in particular the field of English for Specific Purposes. He has been involved in integrating English language skills into project-based engineering courses over the last five years.

Corresponding author

Nathan Dunbar
Otago Polytechnic
Dunedin, New Zealand
+64-21-732089
nathand@op.ac.nz

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AN ENGINEERING WORKSPACE FOR INTEGRATING SUSTAINABILITY APPLIED RESEARCH INTO LEARNING

Chee Siaw Soon, Eunice Goh, Hannah Gardner, Wang Yadong, Leonard Loh, Choo Keng Wah

Diploma in Nanotechnology and Materials Science, School of Engineering, Nanyang Polytechnic Singapore.

ABSTRACT

With the advancements in the fields of nanotechnology and material sciences, engineering students from the Diploma in Nanotechnology and Materials Science (DNMS) in the School of Engineering, Nanyang Polytechnic, are required to solve complex, interdisciplinary and multidisciplinary problems. A new engineering workspace, **N**anotechnology and **A**dvanced Materials **T**eaching facility for **Ur**ban **E**nvironments (NATURE) was set up to provide inter- and multidisciplinary learning opportunities for students from different disciplines: engineering, materials, information technology, health sciences, chemical and life sciences and agronomy. This paper describes how NATURE is used as a platform to integrate sustainable technology applied research into the curriculum of the DNMS. The aim is to nurture students' inquiring mind and to develop their research skills as well as problem identification and problem solving skills. This paper also discusses the effectiveness of this platform to allow lecturers, students and industry partners to work collaboratively on multidimensional interdisciplinary applied research projects in NATURE, thus making learning more experiential and engaging for students. Finally, this paper highlights the challenges faced and provides recommendations for future adoption of this approach in general engineering education.

KEYWORDS

Collaboration between Academia and Industry, Engineering Workspaces, Faculty Development, Learning Environments, Standards: 6, 7, 8.

Notes: *1) In the context of Nanyang Polytechnic, the term 'course' refers to a 'program' while the term 'module' refers to a 'course'. For example, Diploma in Nanotechnology and Materials Science is a course; Materials Science is a module.*

2) Interdisciplinary studies refers to the integration of knowledge from different disciplines, for example combining the knowledge from the fields of engineering with chemical and life sciences.

3) Multidisciplinary studies refers to the study of different subjects within the same discipline, for example learning of chemistry and materials science are essential for students in DNMS. Multidimensional interdisciplinary learning refers to learning *in various forms such as lecture, projects, applied research programmes outside of a structured classroom and industrial collaboration.*

MOTIVATION

The Diploma in Nanotechnology and Materials Science (DNMS) in the School of Engineering, Nanyang Polytechnic (NYP) offers interdisciplinary studies covering science and engineering know-how on materials that are at the nanometre scale. The students acquire knowledge and skills in these disciplines and are able to apply them in developing new materials and applications. To imbue these knowledge and skills to our students in supporting Singapore's manpower needs and economic growth, we reviewed our curriculum in 2014 by conducting an industry landscape scan and gathering feedback from the government agencies.

Through this process, we identified emerging fields that are important to the industry in Singapore, including energy harvesting and storage, water treatment, thin film and coatings as well as environmental sustainability. In addition, one of the recent key initiatives by the Singapore government was the Sustainable Singapore Blueprint (The Sustainable Singapore Blueprint 2015). Singapore has made significant inroads into the sustainable technology market in a short span of time. The government has committed over $4 billion for a 5 year plan starting from 2016 under the RIE2020 plan to support technological capabilities such as aerospace, electronics, medical technology manufacturing and urban solutions & sustainability, with advanced materials identified as one of the key enablers that cut across these areas. SPRING (an enterprise development agency for small and medium size companies) identified several important enablers including advanced materials and nanotechnology which they were targeting to take Singapore's manufacturing industry to the next level.

In aligning with the industry and to support the government's initiative to build a Sustainable Singapore, a new specialisation on Materials for Sustainable Technology was introduced as a third year specialisation in the Diploma in Nanotechnology and Materials Science. The set-up of the workspace was an essential component to assist with the training of our students for this specialisation.

The motivation in setting up the workspace in sustainable technology were guided by several needs:

1) *Real-World Contextualisation and Active Learning*: NYP's curriculum is driven by an outcome based approach which is to produce industry-ready graduates. The facility was envisioned to be a space not only for training of students in their course work and in their projects, but to also allow students to have an experiential environment which simulates the real-life needs of working with people from the industry.
2) *Integrated Learning Experience*: One of the issues often faced by students is to link the fundamentals taught in school with actual application. A laboratory can provide useful hands-on work for students, but has limitations and may be focused in scope. By having a workspace where students are encouraged to participate from the first year of their studies in portions of the projects in the workspace, will allow them to appreciate the fundamentals taught better.
3) *Interdisciplinary and Multidimensional Learning*: Sustainable technology is a field that cuts across various disciplines and a project often requires teams from the various fields to work together. The concept was to design a workspace which acts as a focal

point which will allow interdisciplinary and multidisciplinary collaboration among students, staff as well as industry.

The following sections describe the approach we took to innovate a learning environment based on CDIO standards 6 (Engineering Workspaces), 7 (Integrated Learning Experiences) and 8 (Active Learning).

NYP OUTCOME BASED LEARNING APPROACH

Several set principles are used as a guide in developing the curriculum for the Diploma in Nanotechnology and Materials Science (DNMS). The overall aim at NYP is to provide students with an education that is driven by present and anticipated industry needs, so as to produce industry-ready graduates who are professionally proficient, competent in 21st century skills, innovative & enterprising and socially responsible. These attributes will assist them in making greater valued contributions to the Singapore economy and society upon graduation.

The School of Engineering at NYP developed curriculums based on the CDIO principles and guidelines (Crawley, Malmqvist, Östlund, & Brodeur, 2007) (Choo, Tan, Chong, Kwek, 2015). An outcome-based learning strategy to design an applied learning curriculum (Figure 1) was used where the instructional and assessment strategies are designed to align with the intended outcome. The instructional outcome in turn should meet the module outcome which will also be needed to meet the intended course outcome.

To further strengthen the learning process for the students, the course curriculum design for the DNMS also uses an integrated applied learning curriculum design approach. Students are exposed to integrated learning where the modules are interlinked and connections made between subjects learnt within the semester and through-out the 3 years' of study using a structured categorisation of modules. Students' fundamentals are grounded in the first year through the basic mathematics and sciences. In their second year, materials are introduced to students, linking back to what was studied in the mathematics and sciences, such as Chemistry and Physics. Mini-projects are devised using knowledge gained in the previous semesters where students can conceptualise ideas based on their knowledge learnt. The application of materials are introduced in various fields through different specialisations such as Materials for Sustainable Technology (MST) or Advanced Electronic Materials and Semiconductor Technology in their final year of studies.

The introduction of a specialisation in Materials for Sustainable Technology was recently included due to industry needs and the strong shift towards sustainability and use of green technology. In the emerging field of sustainable technology, as with many real-life applications, it is often multidisciplinary and multidimensional. To assist with providing the intended outcome of producing industry-ready graduates in the field of sustainable technology with the graduate attributes mentioned above, the set-up of a workspace was important. The workspace will provide opportunities for the students in multidisciplinary learning which can enable them to possess multidisciplinary perspectives and be professionally proficient to work with different people with different backgrounds to solve real life sustainable technology problems. It will also train them on essential skills in critical and inventive thinking which will enable them to generate innovative solutions through the awareness of global, industrial and environmental issues as well as develop an understanding of compassion to the community which provide relevance to sustainable technology.

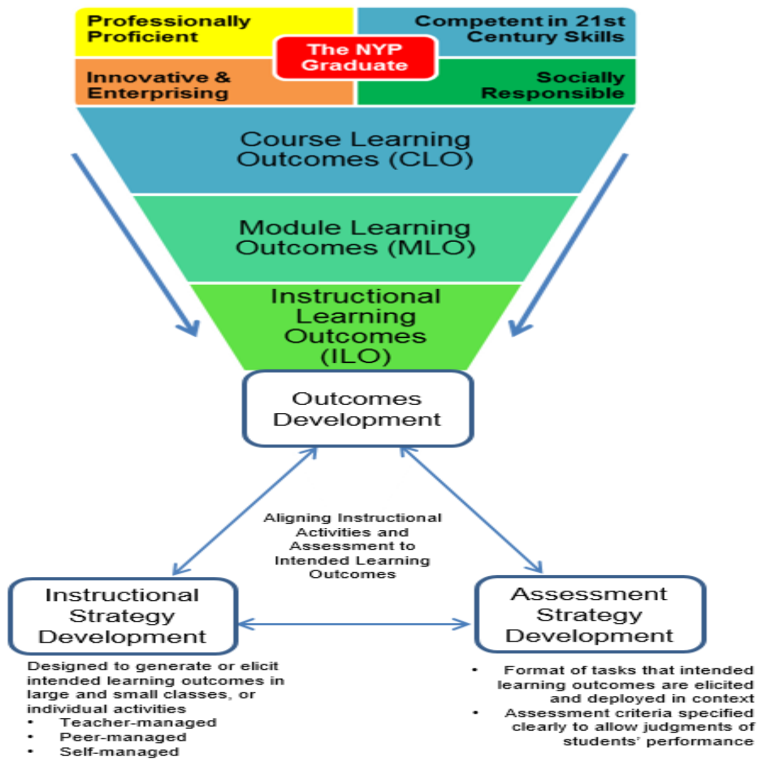

Figure 1: NYP adopted an outcome-based approach to design an applied learning curriculum.

METHODOLOGY

Our integrated curriculum provides a basis of guiding our students through the many modules within their curriculum, and providing a link between modules. However, students in the first and second years tend to have a harder time putting into context the theories learnt using the traditional approaches to teaching and learning pedagogy. Traditional approaches to teaching and learning at the tertiary levels come in the form of lectures, tutorials and laboratories. The learning format in the lectures and tutorials help to provide the necessary fundamentals and theoretical knowledge to students, but may not provide the necessary avenues for them to link to real-life scenarios and applications. This is particularly important from an engineering context as graduates from engineering programmes need to apply their knowledge to applications and products.

A Novel Engineering Workspace: NATURE

To achieve the intended learning outcomes in the area of Materials for Sustainable Technology, an experiential learning space, termed as **N**anotechnology and **A**dvanced Materials **T**eaching facility for **Ur**ban **E**nvironment (or NATURE) was set-up. NATURE is a sustainable facility which incorporates urban farming with alternative, renewable and environment technologies. The objective was to create an integrated research and teaching & learning environment for module delivery and interdisciplinary collaborative research in the field of advanced materials for sustainable living, renewal energy and environment management. The knowledge based needed within this facility covered a wide range from materials, electrical and mechanical engineering, information technology, agronomy, chemistry and food science. There has been earlier reports of greenhouses set up for educational purposes in the US for high school students (Rothenberger & Steward, 1995) and tertiary education (Franklin, 2008), and these were specific for the training on agricultural and horticultural technologies.

Several pedagogical initiatives were implemented in this living laboratory facility whilst aligning to CDIO standards (CDIO Standard 2.1). Figure 2 highlights the key initiatives and projected outcomes for our engineering workspace pedagogy. This living facility served as an Engineering Workspace (standard 6) which allowed students to have more hands-on experience on real life technologies in the facility. This engineering workspace also provided integrated learning (standard 7) experiences as diverse technologies are housed in the engineering workspace. The workspace encouraged interdisciplinary collaboration through collaborative project work within and across different schools and multidimensional collaboration between individuals, academic departments, community and industry. The incorporation of the students' involvement from the first year (where they are taught the fundamentals in sciences, mathematics and materials), helped students make connections with the knowledge learnt in the curriculum. The real life technologies in the facility which promotes industry collaboration and also enhanced active learning (standard 8) as students were engaged directly in critical thinking in solving real life problems. The availability of this living laboratory facility provides a user-centric, open-innovation ecosystem which influences the experiential learning significantly.

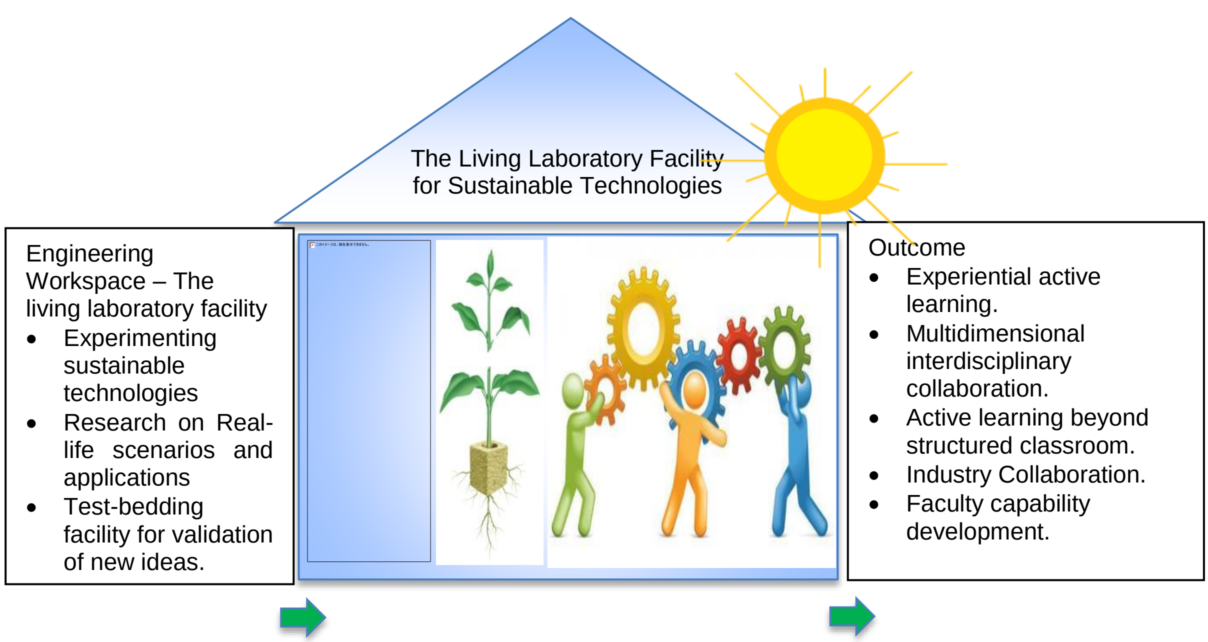

Figure 2: Key initiatives and projected outcomes for the sustainable technology engineering workspace.

A Facility and Platform for Interdisciplinary Project

NATURE is a 9 m by 6 m greenhouse with a height of 4 m, built with sufficient space to facilitate teaching a class of about 25 students, which is the equivalent size of one tutorial or laboratory group (see Figure 3). The main feature is a novel space-saving automated vertical farming system suitable for urban environments which allows a controlled growing environment within an enclosure. Two 3 m high rotating vertical crop stack systems with 12 stacks with a foot-print of 3.75 m by 1.5 m each, allow increased land use and a recycled water tank. The recycled water is used to provide automatic crop irrigation and a water wheel is used to power the rotating crop stack. NATURE runs on low carbon and low power, where the only power required is for the pump to circulate the water in the baths. Rotation of the towers are by gravity administered by the circulation of the water from the water wheel. This concept also requires low water supply, significantly less than a farm of the same area (Sky Greens, Singapore). NATURE also houses smaller test systems for aquaponics, aeroponics, hydroponics and traditional soil beds as well as solar and battery energy harvesting applications.

Figure 3: The new engineering works learning space, termed as **N**anotechnology and **A**dvanced Materials **T**eaching facility for **Ur**ban **E**nvironment (or NATURE).

CURRICULUM DESIGN AND PEDAGOGICAL APPROACH

A Contextualised Curriculum

According to CDIO Standard 1, the appropriate context for engineering education must be provided as graduates from engineering programmes need to apply their knowledge to product, process, and system lifecycle development and deployment.

Several pedagogical initiatives that align to this principle have been implemented using NATURE as a training platform which is meant to provide a student-centric, open-innovation ecosystem, contextualised environment that enhances the learning experience of the students from the first year of their studies.
These include:

- Introduction of active learning within the space

- Experiential learning through hands-on work in this living laboratory facility
- Interdisciplinary collaborative projects among students

An Outcome-based Approach

As discussed earlier, NYP adopted an outcome-based approach to designing an applied learning curriculum. Figure 4 shows the module learning outcome for Sustainable Materials Technology. In the past before the existence of NATURE, students learn the concept and knowledge via lectures or tutorials. With the various sustainable technologies housed within NATURE, the engineering workspace enhanced students' learning experiences by showing the actual application of materials usage in energy and environmental applications. This helps to provide students' more hands-on experience and also promote active learning. Students are able to appreciate the knowledge learned from the lecture and apply into real-life application.

S/No	Module Learning Outcome	Mapping to Student Learning Outcomes				
		EGDF13				
1	Recognize the various types of ecological footprint	l, n				
2	Understand the environmental impacts of materials and chemical processing	l, n				
3	Able to evaluate and critically assess environmental life cycles of various materials.	b, l, n				
4	Understand the application of advanced material usage in energy and environmental applications.	b, l, n				
5	Understand the water treatment technology for industrial and municipal wastewater treatment using conventional and advanced oxidation technology	b, l, n				

Figure 4: Module learning outcome for Sustainable Materials Technology.

All students from DNMS will do their Full Time Semestral Project in their final year of study in NYP. NATURE serves as test bedding facility to enable students to validate the ideas of their project. An example of a final year student's material project is one related to agronomy where students work on increasing the potential yield in urban farming and at lower costs compared to today's commercial technologies available. The students also gain a better understanding of the problems faced in the real-life scenarios of a living lab. A more controlled environment together with the automated irrigation system provided by the greenhouse mean the results from the studies conducted by the students are more conclusive and convincing.

Figure 5: Student and staff involved in a project on wavelength shifting nano-coatings for increased plant growth and yield.

An Integrated Learning Experience

About 70 % of our students at the School of Engineering undergo 12 weeks of a full time semestral project and 12 weeks of internship in their final year of studies. The remaining 30 % undergo 24 weeks of internship. An average of 60 % of the DNMS students work on final year innovation projects related to NATURE since its construction in 2016. One of the key final year student project is in the area of materials development of nano-coatings which help shift the sunlight wavelengths that is essential for plant growth. The nano-coatings are placed onto trays on the vertical farming system and students study the effect of nano-coatings on plant growth. Plants are no longer grown in a laboratory environment but in an actual greenhouse. Another project is in the development of a self-sustainable zero energy facility for greenhouse with the utilization of a solar and energy storage system. This involves the optimization of solar PV and battery systems, battery charging/discharging algorithms, energy monitoring dashboard among others. High performance battery electrode materials are investigated and tested on the system. This incorporates knowledge in the fields of mechanical, electrical and materials engineering. Self-cleaning coatings using materials synthesis and coating knowledge are also developed to address the adhesion issues on the substrate. Agricultural sensors such as environment, nutrients and water levels are being developed, requiring the harnessing of knowledge in materials, agriculture, electronics and programming from various departments. These projects showcase and allow our students to be exposed to real-life issues in modules such as “Smart Materials”, “Sustainable Materials & Technology” and “Energy Harvesting and Storage” where lab sessions are conducted in NATURE. Group project meetings are conducted weekly where students and supervisors related to NATURE projects come together for discussion and for students to share with staff and fellow students’ different view-points. This allows sharing of ideas and information from the various groups.

To incorporate the use of the workspace for first and second year students, applied research programmes are introduced outside of structured classes to nurture critical thinking and brainstorming skills that are important for building the creativity and innovative thinking. These skillsets are often difficult to impart through structured environments. This programme called the *Young Researcher Programme*, is our applied research programme designed to encourage integrated learning for the three-year curriculum focusing on sustainable technology. In this programme, the students assist with various sustainable technology projects from the first year. This helps to incorporate the practical knowledge needed and provides an added informal channel for the added dimension of blended learning to their course work. Students participating in the Young Researcher Programme are given mini-projects relevant to their level of knowledge in various areas of sustainable technology within NATURE. The students are also awarded Co-Curricular Activities points if they have met certain criteria set-up in the programme. This not only encourages students to participate in this event but also provides them with the incentive to put their best efforts into the programme. Two runs of this programme has seen overwhelming response from students wanting to participate in this programme and has also seen an increase in the number students choosing a NATURE project as their full time semestral project.

By creating fun and interactive activities within NATURE, students are indirectly infused with building a sustainable technology mind-set due to the nature of the projects and activities. This helps in bringing a deeper level of appreciation needed in social responsiveness. Based on feedback, students involved in the NATURE sustainable projects during their full time semestral projects as well as those participating in our Young Researcher Programme find the workspace a useful resource in honing their innovative mind-set as they find it more exciting working in an actual sustainable environment compared to the confines of a typical lab space.

An Active Learning Environment

Active learning aims to engage students directly in the learning pedagogy to promote higher order thinking and learning. NATURE has also been used as an active learning tool within the core modules in our curriculum.

Students from DNMS conduct their lab classes on solar technology in the Energy Harvesting and Storage module where they are able to do real-time measurements at NATURE. By conducting the class in NATURE, they get to appreciate how real-life constraints capacity requirement, shading profile, system efficiency and available space affect the solar measurements and parameters. NATURE has also been used as a facility for 50 students from various diplomas in their mini-projects as well as in integrated-multidisciplinary projects as inspiration for exploring innovative ideas for projects.

Students from the Diploma in Electrical Engineering with Eco-Design had used the facility to conduct real-time measurements of the power demand of the NATURE greenhouse as well as perform systems design for the solar and energy storage system as part of their full time semestral projects. The students were able to consider and incorporate the real-time constraints in their system design. This allows them to better appreciate the design methodologies taught in the classroom. They also have the opportunities to develop a test-bed system to verify their design specifications. Once the actual system has been installed, the students will be able to monitor and analyse the energy supply and demand in the NATURE greenhouse while developing innovative energy management solutions to overcome problems related to supply and demand fluctuations.

Prior to the set-up of NATURE, these classes are conducted in indoor labs with simulated set-ups. By using NATURE as a workspace, the students were able to conduct solar cell design and characterisation in more realistic scenarios.

A Platform for Collaboration

Due to the multidisciplinary nature of the greenhouse facility, several technology related capability development projects were initiated. The major knowledge base required for NATURE in material studies and agronomy saw the sharing of knowledge between the School of Engineering for materials development and School of Chemical and Life Sciences in agronomy. Projects in the area of soil bed studies have been conducted using alternative materials like biodegradable polymers which will allow the infusion of fertilizers and natural pest control solutions such as for anti-dengue which will have a time release mechanism. Biodegradable plant pots are also being developed which allow the seedlings to be transferred to bigger pots without the need for transplanting. These studies need to be coupled with the understanding of plant physiology and factors affecting the growth of the plants. This engineering workspace also serves as a test-bedding facility for validation of new ideas.

The facility has also been used by Occupational Therapy students from the School of Health Sciences as part of their classes in Gardening Therapy, the Diploma in Chemical & Green Technology in training on Aquaponics and the use of the organic drying chamber. Vegetables and herbs are grown and supplied to the Diploma in Food Science and Nutrition for their classes and their feedback as well as tools in characterising food can help in improving the growth of the crops as well as provide knowledge from different disciplines to students who otherwise would not have access to.

Since its construction, NATURE has encouraged various industry partners to collaborate with the school and provide opportunities for students to solve the real life problems. Companies have approached NYP to place their systems at NATURE to conduct trial runs. Students are able interact with the industry and work on industry specification requirements and timelines. We often include our students in project discussions with companies, and also provide them with the specifications and requirements set by companies for their projects. This provided excellent means for the students to appreciate project management as well as the softer skills requirements that are needed when working with industry. This exposure has provided students with the opportunities to build on their 21st century skillsets and improve and understand the professional proficiency needed when interacting with industry.

RESULT AND FINDINGS

A survey was conducted to students who were involved in a range of activities that NATURE had to offer.

A survey was conducted for MST specialisation class of 22 DNMS students who had a laboratory session on solar cell characterisation in the Energy Harvesting and Storage module at NATURE, 19 students responded to the survey. The survey was done in a paper format and a few questions were asked in the survey (see appendix A). 95 % found that a realistic sustainable facility helped with their understanding of sustainable concepts taught in class. It was found that the students who did not gain as much knowledge were those students who were previously involved in projects in NATURE.

Another question asked was how students rate their knowledge and hands-on experience gained in comparison to prior knowledge before their activities in NATURE. The rating of the knowledge and hands-on experience gain was categorized into “Significant”, “Reasonable”, "Marginal" and "Not at all". None of the students selected "Not at all", 63% of students found they had gained "Reasonable" knowledge and hands-on experience, 16% and 21% of students found they have gained "Significant" and "Marginal" knowledge and hands-on experience respectively. In addition, 100 % of the students were in agreement (with rating of "Excellent", "Very Good", "Good", "Poor" and "Very Poor") that the NATURE facility provided a good hands-on experience, with 53 % of students rated "Very Good" and 26% of students rated "Excellent" (Figure 6).

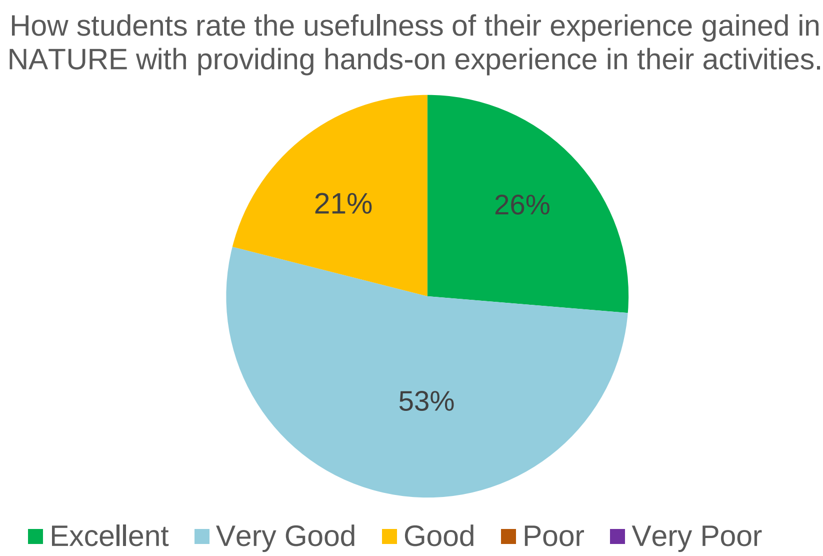

Figure 6: Student survey on usefulness of NATURE in providing hands-on experience as a laboratory class.

In addition, another survey was conducted with students who had used the living laboratory facility for their full time semestral projects. This survey was conducted as an online form using Google form. The questions asked were similar to the survey in Appendix A. 10 students were invited to participate and 6 students responded. The students were asked how their knowledge gained in Sustainable Technology before and after their experience using NATURE. 100 % of the students were in agreement (with rating of "Excellent", "Very Good", "Good", "Poor" and "Very Poor") their knowledge gained after using NATURE for their full time semestral projects. 67 % of students rated their knowledge gained in sustainable technology related to agriculture "Very Good" and about 16.7% of students found their knowledge in this area improved to "Good" and "Excellent" respectively (Figure 7). All students agreed that the NATURE facility is a real life engineering platform to provide students a more hands-on learning experience.

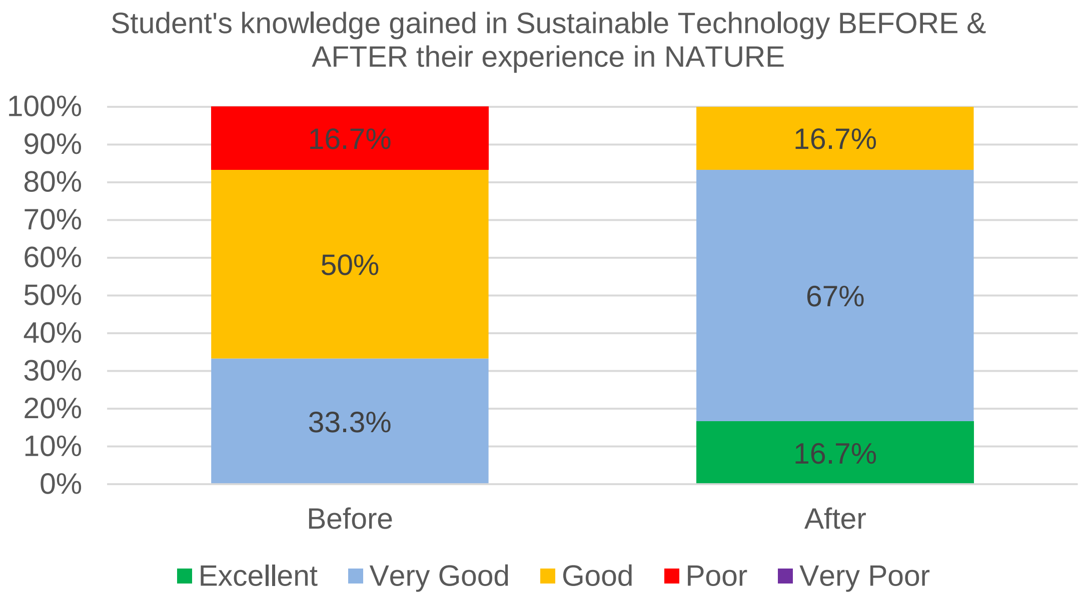

Figure 7: Student survey on knowledge gained in sustainable technology through their experience in NATURE.

In addition, all students agreed that they have gained more knowledge and hands-on experience after involving in NATURE. With rating of "Significant", "Reasonable", "Marginal" and "Not At All", figure 8 has shown 50% of students found their knowledge and hands-on experience had significantly improved after using NATURE as an experimental workspace for their full time semestral project; 33% of students found their knowledge and experience had a reasonable gain and another 17% found marginal gain in his/her knowledge and experience. Different knowledge and hands-on experience gained by students could be due to the difference in the students' project scopes. All of them however unanimously agreed that they will encourage their friends to join activities related to NATURE.

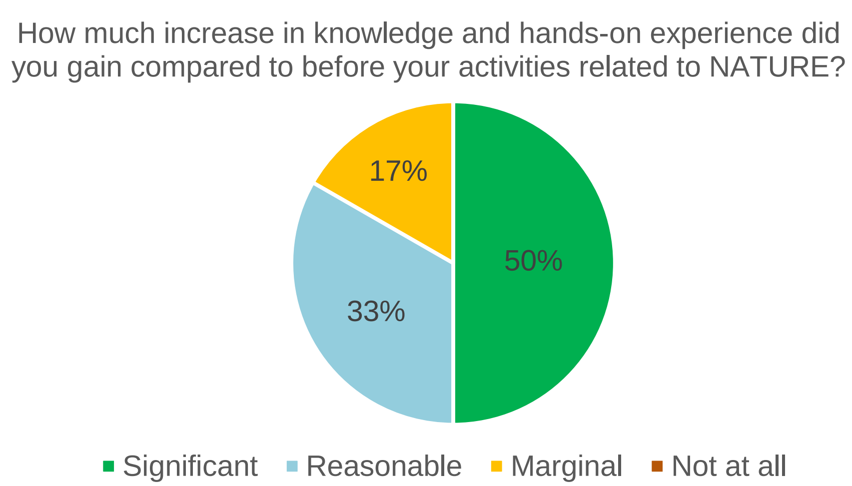

Figure 8: Student survey on their knowledge and hands-on experience gained due to activities related to NATURE.

In order to teach and mentor students in the multidisciplinary platform, lecturers are working with government agencies and industry partners to acquire knowledge and skills that are currently used by industry. This platform has also helped lecturers to bring relevant examples to the students and improve both their soft and technical skills outside of their respective disciplines. Lecturers share their experience with peers through Sharing Organisational Learning Interaction Dialogue (SOLID) sessions which foster the spirit of continuous improvement and professional development.

A survey was conducted to staff who were involved in NATURE. This survey was conducted as an online form using Google form, the questions asked were similar to the survey in Appendix A. Total of 7 staff were responded to this survey. Staff were asked how they rate their knowledge gained in sustainable technology after their experience in NATURE with rating of “Excellent”, “Very Good”, “Good”, “Poor”, “Very Poor” and “Not applicable”. The survey has shown that 86% of staff found that their knowledge in sustainable technology improved (majority from “Poor” or “Good” to “Very Good”) after their experience in NATURE. One staff (14%) found his/her knowledge improved from “Good” to “Excellent” after his/her experience in NATURE (Figure 9). All staff agreed that this facility has encouraged more collaborations with industry partners and provided opportunities to develop their capability and competency. By working with industry partners, it helps to keep their professional knowledge and skills in sustainable technology up to date. The effectiveness of the survey for staff can be improved by sending to more staff involved within and across different schools which the team are looking to improve in this area.

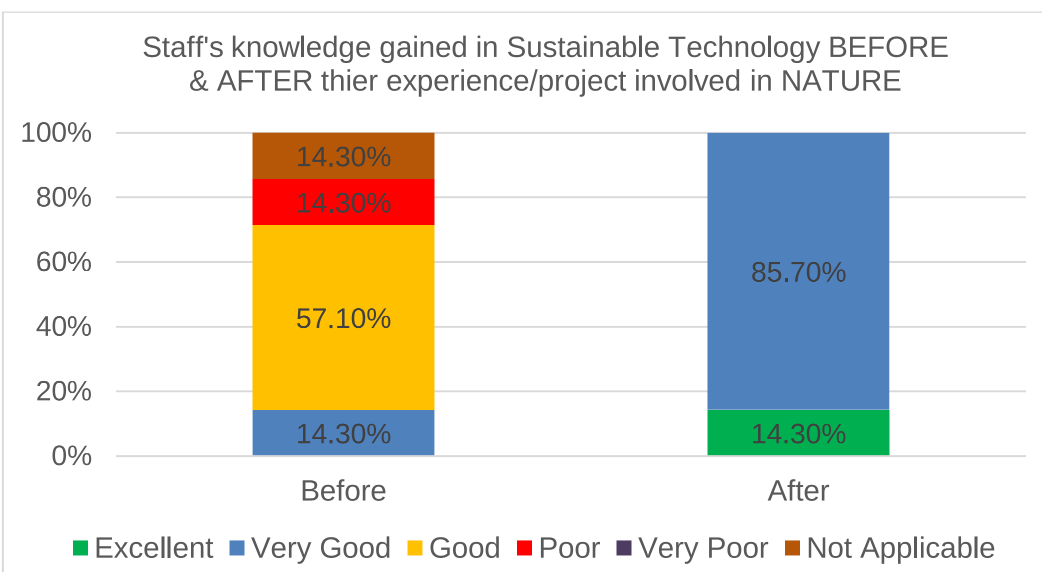

Figure 9: Staff survey on knowledge gained in sustainable technology before and after their experience/project involved in NATURE.

CHALLENGES

There has been several challenges faced in the set-up and running of NATURE. The main challenges faced were: i) being able to focus on selective industry current technologies suitable for training within the confines of the 6 m x 9 m engineering workspace; ii) management of resources in different technologies and skillsets; iii) as well as preventing misuse of the facility.

To set-up and run an interdisciplinary and multidimensional engineering workspace is not easy as it involves a lot of resources. It is important to show the engineering workspace is aligned with the needs of the emerging field identified as important to Singapore. There are various sustainable technologies available but not all can be housed within one engineering workspace. Selection of suitable sustainable technologies which aligned with the needs of emerging field and module outcome are thus important. Technologies proposed were reviewed and selected based on the importance to industry and the ability it can be translated into the training for our students.

With several stakeholders involved in the facility, planning and management of the resources can be a challenge at times, requiring guidelines, procedures and rules to be set in place for the effective running of the facilities. Maintenance of the hardware and facilities and training in the proper use of the facility are very important elements to ensure the success of the facility. These challenges were minimised by creating shared responsibility of all parties involved as well as by enlisting the help of student assistants in the running of the facilities. We employed student assistants who were made on an hourly basis in assisting with the maintenance of the facility. Students involved in the Young Researcher Programme also provided assistance in managing the resources. Staff involved in each field of work were also responsible in their area of work. For example, staff from the School of Chemical and Life Sciences involved in Aquaponics were responsible for their equipment, plants and fishes housed within NATURE.

Our NATURE workspace has become more popular among students and staff, with many expressing their wish to use the facility in their teaching and learning as it serves as a very useful platform to allow students to appreciate the knowledge learned from fundamentals taught in lectures and provide students with more hands-on experiences to solve real life problems. With this increase in people with different disciplines and activities occurring in NATURE, one of the challenges faced was the invasion of pests. Pests affect the plant's health which could influence the results of the experiments conducted in the greenhouse. To minimise this from occurring, a controlled access to the NATURE was implemented to protect the misuse of facility by unauthorized and untrained personnel. Relevant training is required to be conducted for any staff and student using the facility. Having controlled access increased inconvenience for the people using the facility but was however deemed necessary to prevent greater challenges that can occur from improper use of the facility. Training sessions were conducted on a regular semester basis for new users. Records were also kept on the movement of personnel. The occurrences of pest infestation has been reduced drastically and none have so far been attributed to improper use of the facilities.

One of the key pedagogical parameters important in the setting up of this workspace was to understand the impact this workspace has on the outcome of the students. This engineering workspace was set-up just over a year ago, with the initial idea to focus on sustainable technologies for DNMS. Surveys and studies were set-up for students relevant to this area. In this short span of time, there has however been many potential experiential active learning opportunities in other areas and requested by different diplomas and schools. A standardized or a more structured feedback have yet to be established and used by people who have used this facility as part of their teaching, learning or projects from other fields and schools. In order to achieve a more comprehensive study on the effectiveness of this engineering workspace, we are currently are in the process of developing a suitable feedback that can be used prior to and as part of the training or projects which will cover all users in NATURE.

CONCLUSION AND REFLECTION

This paper has described how a new engineering workspace (NATURE) has provided inter- and multidimensional Interdisciplinary learning opportunities for students from different disciplines. This paper has also shared how NATURE is used as a platform to integrate applied sustainable technology research into the curriculum of the Diploma in Nanotechnology & Materials Science, and allow lecturers, students and industry partners to work collaboratively on multidimensional interdisciplinary applied research projects. The pedagogy approaches applied are aligned with Standard 6, 7 and 8 of the CDIO standard, where an engineering workspace is set up to promote active and integrated learning experience for students.

Having various sustainable technologies under one roof is challenging but yet provided an active experiential learning for various diplomas and indeed a multidimensional Interdisciplinary platform which benefited students with different backgrounds. Based on the students' feedback, this engineering workspace has met its objective by providing more hands-on learning experiences and opportunities for the school in implementing integrated learning. In addition, this workspace has encouraged more industry collaborations which allow the students to work on real life problems.

There are various challenges faced when setting-up and in the running of the operations of this engineering workspace. Some of these challenges in resource management has been overcome with a structured plan. A detailed study on the impact the workspace has on the outcome of the students from various disciplines has a yet to be conducted but has been planned.

Overall the experience with NATURE has been positive and are welcomed by all students, staff and industry partners. We will continue to document the results of implementation to formulate a more detailed study on the effectiveness of using this engineering workspace as part of our teaching and learning pedagogy.

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BIOGRAPHICAL INFORMATION

Chee Siaw Soon, is a Lecturer in the Advanced Materials & Nanotechnology section within the Biomedical & Materials Group, School of Engineering at Nanyang Polytechnic, Singapore. She is involved in teaching several areas of materials science and conducts research and industry collaborations in the field of polymeric nanocomposite for sustainable technology and applications.

Eunice Goh Shing Mei, Ph.D. is a Lecturer in the Advanced Materials & Nanotechnology section within the Biomedical & Materials Group, School of Engineering at Nanyang Polytechnic, Singapore. She is involved in teaching materials science and engineering subjects. Her main interests are in the areas of educational research and innovation in materials applications.

Hannah Gardner, Ph. D. is a Lecturer in the Advanced Materials & Nanotechnology section within the Biomedical & Materials Group, School of Engineering at Nanyang Polytechnic, Singapore. She is involved in teaching several areas of materials science and conducts research and industry collaborations in the field of functional nanomaterials.

Wang Yadong, Ph. D. is a Lecturer in the Advanced Materials & Nanotechnology section within the Biomedical & Materials Group, School of Engineering at Nanyang Polytechnic, Singapore. He is involved in teaching several areas of materials science and conducts research and industry collaborations in the field of nanomaterials for sustainable technology and applications. He has published over 50 top quality international journal papers.

Leonard Loh, Ph. D. is a Senior Manager in the Advanced Materials & Nanotechnology section within the Biomedical & Materials Group, School of Engineering at Nanyang Polytechnic, Singapore. He is the Course Manager for the Diploma in Nanotechnology & Materials Science, overseeing the design and implementation of the diploma programme. He is also involved in the area of research in the field of Nanomaterials for sustainable technology.

Dr Choo Keng Wah is a Deputy Director in the School of Engineering. He is actively involved in industry project development and management, research and development project, commercialization of IPs, engineering education benchmarking, education quality assurance and accreditation.

Corresponding author

Ms. Chee Siaw Soon
Nanyang Polytechnic
180 Ang Mo Kio Ave 8
Singapore 569830
+65-65500942
Chee_Siaw_Soon@nyp.edu.sg

APPENDIX A: SURVEY CONDUCTED IN PAPER FORMAT

Nanyang Polytechnic

For *NYP students* Only

SURVEY FOR NATURE RELATED ACTIVITIES

Enrolment Year : ____________ Diploma : ________________________________

Name (Optional) : ____________________________ Sex : M / F E-mail (Optional): ______________________

1. How do you rate your knowledge on Sustainable Technology and Technology related to Agriculture before your experience in NATURE?
   [ ] Excellent [ ] Very Good [ ] Good [ ] Poor [ ] Very Poor

2. What kind of activities were you involved with NATURE ? (You can select more than one)
   [ ] Class [ ] Project [ ] Interest Group [ ] Club/Committee [ ] Others : ________________

3. How much increased knowledge and hands-on experience did you gain compared to before your activities related to NATURE?
   [ ] Significant [ ] Reasonable [ ] Marginal [ ] Not at all

4. How do you rate the usefulness of the experience gained at NATURE with providing hands-on experience in your activity?
   [ ] Excellent [ ] Very Good [ ] Good [ ] Poor [ ] Very Poor

5. If you have used NATURE for a classroom activity, did the practical session in a realistic greenhouse setting in NATURE help with the understanding of the concepts taught in class?
   [ ] Yes [ ] No [ ] No Difference

6. If you have used NATURE for projects, did NATURE provide a useful facility for your experiments and prototyping of your project?
   [ ] Yes [ ] No [ ] No Difference

7. Did the activities you have done in NATURE motivate you to want to learn more or select a project in a relevant area of Sustainable Technology or Agronomy?
   [ ] Yes [ ] No [ ] No Difference

8. Would you encourage your friends to join activities in NATURE?
   [ ] Yes [ ] No

9. Any additional comments?

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____

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SEARCHING FOR SYMBIOSIS: OPPORTUNTIES AND OBSTACLES IN FORMULA SAE TEAM/SCHOOL ADMINISTRATION RELATIONSHIPS

Michael L.W. Jones

Professor, Communication, Culture, Information and Technology, Sheridan College

ABSTRACT

While engineering student project-based learning teams are primarily focused on their main goals, they also operate within the larger administrative context of their home school. In an ideal world, team and administration goals are symbiotic and furthered by mutually supportive policy and action. However, there are many potential points of contradiction between a team's goals and the concerns of the school's larger administration. Student team leaders often face the daunting task of managing their workflow while balancing administrative and legal priorities that may seem counterproductive or even hostile to team goals. Given the unequal power relations at play, ignoring administrative goals is often not an option - failure to comply to administrative rules and norms can lead to consequences that can threaten the team's very existence.

This paper highlights examples of team/administration cooperation and conflict from a particular PBL team context – Formula SAE (FSAE) automotive racing teams. Members of teams participating in the North American FSAE competitions from 2013-2015 shared specific stories of team/administration cooperation and conflict in written surveys and competition site interviews as part of a larger dissertation research project. Team experiences with administration vary from symbiotic, supportive relationships to ultimately detrimental to team success. While a positive relationship with administration doesn't guarantee an FSAE team will be successful, such a relationship does remove significant barriers to team success. This paper suggests CDIO standards provide a framework to help school administrations advocate for the resources that can best assist FSAE and similar student-managed project-based learning engineering teams.

KEYWORDS

Project-based learning, active learning environments, Formula SAE, student project teams, CDIO Standards 3, 5, 6, 7, 8, 9

INTRODUCTION

Student engineering project-based learning teams are intensive learning experiences where groups of students collaborate to achieve specific technical objectives that are often framed and evaluated by external agencies. Consistent with CDIO Standards 5 and 7, students in such teams not only develop applied knowledge of engineering concepts, but also develop critical professional skills such as systems engineering, collaborative work, team leadership, and effective oral and written communication (CDIO, 2018).

This paper suggests one critical management skill team leaders develop is negotiating a balance between team goals and those of their supporting school. Student engineering project-based learning teams require the support of their larger administration. A strong relationship with school administration removes many potential barriers to team success, whereas a problematic relationship with school administration can lead to considerable headaches and even jeopardize the team's existence, given the goals of administration are likely to trump a team's particular needs.

This paper examines findings from survey and interview research done in conjunction with the author's larger dissertation research on information management concerns in one particular project-based learning context, Formula SAE. The primary goal of Formula teams is to design, manufacture, test and race a small formula-style racecar. Student Formula teams have a long history and international reach, with over 500 student-managed teams competing in over 10 intercollegiate competitive events worldwide (FS World, 2018), the largest two of which are sponsored and structured by the Society for Automotive Engineers (SAE). As will be discussed below, Formula SAE teams have varied experiences in dealing with their home institutions that can range from mutually supportive to combative. This paper also argues that CDIO standards can help structure mutually beneficial symbiotic relationships between Formula SAE teams and their larger administration.

THE TEAM/ADMINISTRATION RELATIONSHIP IN THE FORMULA SAE CONTEXT: A CULTURAL-HISTORICAL ACTIVITY THEORY (CHAT) PERPSECTIVE

This research is founded on cultural historical activity theory (CHAT). CHAT is a meso-level theory grounded in human activity and the larger cultural and political forces that enable and constrain it (Engeström, 1987). Developing from roots in constructivist learning (Vygotsky, 1978), CHAT notes that a team's core activity is necessarily constrained by rules, community and division of labor, which pose the possibility for contradictions that need to be attended to in order for the core activity to be successful. As presented previously at CDIO, this theoretical model shows promise as a means of framing research questions across numerous specific case studies (Jones, 2015).

The below diagram represents the six core components of CHAT, visualizing "…the individual practitioner, the colleagues and co-workers of the workplace community, the conceptual and practical tools and the shared objects as a unified dynamic whole." (Engeström, 1991, p. 267).

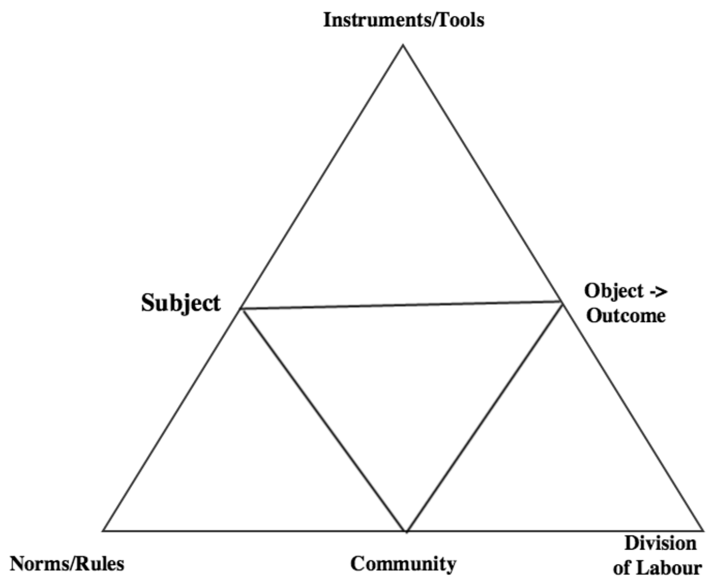

Figure 1: Engeström's representation of cultural-historical activity theory
(adapted from Engestrom, 1987; 1991)

In the top triangle, we see Vygotsky's (1978) construction of a core activity - a relationship between subjects and their intended objects/outcomes mediated by tools (also translated from original Russian to instruments or artefacts). The subject can be either an individual or collective, depending on the level of analysis. As varying instruments/tools may lead to objects of varying quality and value, subjects must reconcile varying results of creative engagement to arrive at objects that best related to intended outcomes.

Complicating matters are the lower components that ground activity in social and historical foundations. *Community* includes all others that may be affected by the subject's desired outcome. *Norms/Rules* (referred to as praxis in some translations) are both written rules and procedures and unwritten norms that govern interaction. These are necessary to mediate social order and help regulate larger questions of justice, ethics, and morality. *Division of labor* acknowledges that power relations are often unequal, leading to political negotiations to ensure the overall outcome of the activity can be attained.

Relations among these six core components can yield many different types of tension, which Engeström (2008) denotes as contradiction.

Table 1: Engeström's outline of contradictions

Contradiction	Description
Primary	Differences *within* a given node in an activity system (e.g., competing interpretations of goals by individual subjects)
Secondary	Differences *between* two given nodes in an activity system (e.g., interactions among subjects, instruments/tools and object)
Tertiary	Change in activities *over time* (e.g., evolution of an activity such that later versions significantly differ from previous)
Quaternary	Differences between *two competing activities* (e.g., two subjects attempting to achieve the same outcome)

(adapted from Engeström, 2008)

An understanding of CHAT and its contradictions helps frame potential research questions regarding FSAE team work and the team's relationship with its home school. While the team uses various instruments/tools to build and refine relevant objects, it does not do so in a vacuum. The team exists in a larger academic community that has its own norms, rules and responsibilities, creating potential secondary contradictions between the core activity and all three of the cultural/political dimensions of CHAT. Given school administrations have broader fiduciary, resources, and legal responsibilities, any serious quaternary contradiction between administration and team outcomes is likely to resolve in favor of administration priorities.

FSAE team leaders must negotiate this web of interrelated factors with caution else larger, more powerful forces beyond their control intervene to suspend team activity. Given that team leaders are often quite focused on their own core activity and might be less versed in the responsibilities and details of their surrounding bureaucracy, there are multiple points of contention and contradiction that may arise. Through survey responses and competition interviews done in 2013-2015 as part of larger dissertation research, team members were asked to reflect on their relationships with their school's administration. Specific reflections are shared here by reference number – an anonymized table of respondents can be found in the larger work (Jones, 2017).

DISCUSSION

While most FSAE team members surveyed or interviewed noted that team/administration relationships were positive, they were often eager to share events that complicated their progress towards the team's core activity. This paper suggests schools that live by the intent of the following CDIO standards (whether members of CDIO or not) are more likely to provide a more supportive environment for their FSAE teams. However, even in such environments, points of contradiction can occur.

Table 2: Relevant CDIO Standards (CDIO, 2018)

CDIO Standard	Description
3	**Integrated Curriculum:** *A curriculum designed with mutually supporting disciplinary courses, with an explicit plan to integrate personal and interpersonal skills, and product, process, and system building skills*
5	**Design-Implement Experiences:** *A curriculum that includes two or more design-implement experiences, including one at a basic level and one at an advanced level*
6	**Engineering Workspaces:** *Engineering workspaces and laboratories that support and encourage hands-on learning of product, process, and system building, disciplinary knowledge, and social learning*
7	**Integrated Learning Experiences***: Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal and interpersonal skills, and product, process, and system building skills*
8	**Active Learning:** *Teaching and learning based on active experiential learning methods*
9	**Enhancement of Faculty Competence:** *Actions that enhance faculty competence in personal and interpersonal skills, and product, process, and system building skills*

Securing Resources

A central concern for all FSAE teams is securing adequate resources to sustain their activity. Key resource requirements include financial support, access to specialized space and tools, and integration of team activities in academic planning and programming. On all three team experiences vary, often considerably.

Financial support is a core requirement for team success. A team starving for resources will find it difficult to secure key materials needed to manufacture the car or have the resources to attend competition. This becomes especially relevant for teams distant from competition venues or those who wish to explore distant competition opportunities. As a result, well-established FSAE teams will dedicate specific team members dedicated to sponsorship, industry liaison and school funding matters. This role is often how non-engineering students become involved with the team's core activity.

While some teams were reluctant to share financial information, enough respondents did respond to paint a quite varied picture of the fiscal landscape. For example, respondent #9 noted an annual contribution of US$60,000 from their school, while #17 and #25 both shared an approximately USD$20,000 figure. Respondent #32 was lobbying the student association to install a student activity fee to raise approximately US$15,000 a year. Faculty advisor #37 said the student association provided US$25,000 in funding, on top of facility support to be noted later.

At the other end of the spectrum, student #43 suggested they were struggling with trying to leverage an initial CDN$5000 administration grant – and this team has since disbanded. While money doesn't necessarily buy success, it is not hard to see how #43's struggles are qualitatively different than #9 or #37's significant outlays. Schools willing to allocate funds for student team success create an environment where team leaders can focus on their core activity without needing to dedicate core resources to fundraising.

Perhaps more essential is access to the space and tools required to legally conduct the core activity of building a racecar. FSAE teams require specialized machinery that come with significant safety and physical plant requirements. It is not an academic activity you can accommodate with a generic classroom. Given space is a key point of conflict in academia, having institutional relationships to secure access to space becomes a point of concern.

CDIO Standard 6 encourages school administrations to provide such spaces. For some teams, access to space and tools happens due to a strong and supportive administrative commitment to project-based learning teams. Facutlty advisor #37 noted:

> "For space, the team has space within what is called the [X], a 24,000 ft^2 space dedicated to the support of our student engineering competition teams. Each team within this space (there are currently 7 hosted) has office space, dedicated build and storage space, and access to the common machine tools. X is open 24/7. It has machine tooling available 24/7, up through 3-axis CNC mill. The school staffs a ½ time machinist/staff support person dedicated to the infrastructure support of the X and its teams." [#37]

This is gold standard practice – and not surprisingly, #37's team is a perennial contender in FSAE competition. However, most teams surveyed or interviewed did not note having full buildings dedicated to project team activity. #43 not only struggled with limited financial support, but a working space that doubles as a loading dock. More common would be the experience of respondent #27, who stated they have "about 800 sq. ft. of dedicated space, but down two alleys – it's actually kind of scary to get there." [#27]. While FSAE teams will make do with what space is allocated to them, a school that actively supports teams with ample and accessible space creates the conditions where team activity can happen with minimal interference.

Another way a school can support a team's activity is through curriculum integration. Some teams are "clubs"– an extracurricular activity not otherwise integrated into curriculum. While one might think club teams are not likely to be successful, this is not necessarily the case – respondent #3 noted his team is a club that does not receive course credit, but is nevertheless one of the perennial contenders in the Michigan competition.

Some schools have a capstone design project course in the final year of their academic program, and team design projects can usually qualify for inclusion. Three respondents (#16, 21, and 23) noted they were presently getting course credit through a capstone course. Outside of formal capstone courses, respondent #8 explained "we do offer an engineering elective for FSAE participation provided certain prerequisites are met (you must have been on the team for at least a year and are currently holding a prominent design role)." [#8]

It should be noted that even where course credit is granted, participation is largely extracurricular. Some team members note full-time job equivalent level workloads on FSAE team work, and others note work done greatly exceeds what is normally done for similar credit hours. However, schools that offer capstone design or elective credit are acknowledging that such project work has value and relevance to the curriculum. This can help defend the project within the context of the academic community, allowing faculty to see this as part of the educational experience versus a club distracting students from their day-today academic work. Offering course credit can help mitigate any contradictions between the core activity of the team and the larger academic community.

CDIO Standards 3, 5, 7 and 8 could have relevance on this particular issue. The more integrated into curriculum an FSAE team member is, the more likely their core activity can be tied to core learning outcomes, and the more likely the program will appreciate and respect the efforts of FSAE members as they engage their core activity. Teams that are designed as “clubs” automatically operate at the disadvantage of being not “real” in the eyes of curriculum planners and administrators.

Navigating Rules and Procedure

A major point of contention can be integrating team activity into the larger bureaucracy of a school’s administration. Student team leaders may not be immediately aware of or sympathetic towards the requirements of their overarching administrative structure. For example, respondent #11 was the point person for internal and external relations for their team, and noted that they spent a lot of time working with “the Foundation”, the unit which handles charitable donations.

> The Foundation requires that we get all external communication approved by them before sending out. This includes newsletters, sponsorship packets, and thank yous. They also require that we report all charitable donations that our organization receives, both monetary and gift in kind donations. It’s been a little difficult to get all team members to get on board with this and get the required forms turned in in a timely manner, however, we are slowly making progress.” [#11]

Her reflection showed no shortage of frustration over such boundary negotiations, but it was equally clear that these negotiations were necessary to process and acknowledge alumni contributions appropriately.

School administrations have their own procedures to track spending and to ensure only authorized individuals can make large purchases. It is likely that students will find these procedures to be barriers to their core activity. Respondent #9 shared this experience:

> “Our biggest conflict with University regulations comes with purchasing. An easy example is when we needed to purchase a new engine: We wanted to buy a CBR500R engine and had $4,500 to do so. We were not allowed to buy an entire bike and pull it apart for the engine and relevant electronics (despite the fact that it fit within our budget) because the University was uncomfortable with our team owning a motorcycle. We ultimately paid $4,000 for the company to pull the engine and electronics for us, which means we over-paid. This year, when we wanted to buy a new engine, one of our team members purchased one out-of-pocket on Ebay and then went for reimbursement to avoid the hassle. The school didn't like it, but it's easier to beg forgiveness then ask permission in cases like this.” [#9]

The above example shows a certain level of resourcefulness in dealing with the intricacies of university administration – but also a willingness to throw the laws of the institution in the garbage. While I suspect sympathetic bureaucrats might be impressed by the above case, there are challenges in disregarding rules and procedure. Consider #23s reflection:

> “We were bored one Friday night and decided to build a compressed air potato gun from some stuff around the lab – we launched a few potatoes at the wall of the lab, splat splat splat. Then launched a few at the football field trying to clear the bleachers. Was fun until the campus police dropped by on reports of explosions. They don’t like us much.” [#23]

When campus police don’t like you much, you may have serious troubles that cause your team to be sanctioned. To avoid bias, not included in this sample was the team behind the author’s first experiences with this domain. While a largely successful and respected team, recent iterations of the team managed to violate internal rules and regulations as to be put on hiatus during the course of this research. Even quality connections to power structures that be are not enough to fend off administrative authority, especially when key rules are broken.

The Mediating Role of Faculty Advisors and Technicians

It is hoped that in such situations is that a strong faculty advisor may intervene, if only to explain away the core activity of FSAE teams. He or she can play a strong mentorship role, help guide exploration in a complex problem space, and help avoid going down backwards paths in project-based learning (Mandin et al, 1997).

As per competition rules, every team must have a faculty advisor, and that advisor is the point person for any official communication regarding rule interpretations or results (FSAE Rules, 2016). However, it is clear from on-site observation that some teams do not have any active faculty support at competition. Respondent #28 could not even name their advisor, but did not seem too concerned: “It’s more a club at our school, so we do our thing. The machining guys at the lab are more helpful – I believe there’s a professor who handles some admin things, but haven’t seen him around at all.” [#28].

While I suspect the team has fun “doing its thing”, an amateur approach to an increasingly competitive event is not likely to yield extraordinary results. In #28’s case, competition scores over the years have been mediocre at best. Without expert input to help students negotiate technical and administrative problems, it becomes that much more challenging to develop a competition-valid design.

That noted, the temptation for some advisors to overreach is real and problematic.

> “It’s kind of an open secret that [Prof. X] does a lot of the core design work at [team A]. Students do a lot of the grunt work, but most of the main design parameters are set in advance at the top. I’d hate to work in that environment – and some of their team members off the record say so, at least that’s what they tell us when he’s not around. I almost went to [school] too – glad I didn’t, I know from meeting X a couple of times we wouldn’t get along.” [#22]

Given scores in the design competition for the team in question, centralizing power does not work well. The advisor in question is indeed well known to try to interfere with design judging, which is explicitly supposed to be a conversation between students and design judges. His over-enthusiasm has jeopardized his team’s ability to faithfully represent their design, to the team’s detriment, and to the point other teams have noticed. As the team in question wasn’t part of the research sample, I cannot confirm from this record – but from informal discussions with previous team leaders of the team in question, #22 is not alone in their observation.

Golding (1999) suggested that the the best role an advisor can play is a mediating role – not interfering with developing subject expertise, but also being aware enough to understand when intervention is necessary. Teams with sufficiently active – but not overly involved – advisors end up receiving the best of both worlds. As noted in CDIO Standard 9, this may require some attention to faculty competencies, as being a "guide on the side" (King, 1993) can be a complex role for experts to fall into.
A potential substitute for the role of advisor is technical staff, noted by eight teams as a valuable resource. Technical staff are often on hand to ensure safe operation of manufacturing tools, and are usually eager to share their specialized knowledge with students eager to learn. #34 was particularly enthused about their school's lab manager:

> "[X] at our machine shop is a god. I've learned so much about machining and how to design for manufacturability from him – stuff I wouldn't get out of regular courses. Spending weekends and early mornings in the lab with him you pick up so many things, and he really cares about people – he kept the lab open extra hours in our manufacturing push totally volunteering his time and we really wouldn't have the car we have without that. He's also funny as hell – I sometimes just drop by to hang out, and I've gone to grab a beer with him after shift a couple of times. He even came to competition last year with his family. Just an awesome supporter of us. We'd be pretty screwed if he left." [#34]

Unfortunately, such staff are not always seen as necessary in the grand design of a department. Shortly after sharing this story, #34 noted, with significant pain, that the manager in question was being let go, as his speciality was determined to be no longer relevant. #34s reaction made it clear how essential front-line technical staff can be when looking at an overall support approach.

Effective institutional support is often a multipronged affair. Technical and administrative staff are often direct contacts and resources for student project teams, and often more accessible than faculty. Standards 6 and 9 vaguely touch on administrative commitment to CDIO activity support, but having a strong supporting cast of support staff is probably the best manner of supporting student project teams. Alas, in many institutions, these jobs are can be tenuous and easy victims to larger budget priorities- but at the direct and negative effect to student project teams.

For many FSAE teams – most of which whom are already operating on tight budget - such hiring and firing decisions are seen as penny wise and pound foolish. High-level administrative decisions rarely take the needs of project-based learning student teams into account while making such choices, but given stories like #34, perhaps they should.

CONCLUSION

This paper looks at specific examples of how FSAE team members perceive their relationship with their administration. Given the context of interviews or surveys in this case, it's arguable that contextual factors may have skewed results to a generally positive report of the team/administration relationship. But even with that assumed bias, team members were happy to report specific problems with school administration.

Ideally, all parts of the institution can work collaboratively towards supporting FSAE and similar engineering student project teams. FSAE teams require financial support, space academic support, and the support of technical and administrative staff. Such an infrastructure immediately removes many challenges FSAE team leaders face. Given many team leaders are just learning how to run such a complex project, the less bother they immediately have to handle, the better.

This paper concludes by suggesting administrations pay special attention to CDIO Standards 3, 5,6, 7, 8 and 9 in developing plans to support FSAE and similar teams. This paper also fully admits that doing so will not guarantee FSAE or other project team success - but it cannot hurt.

To end on a personal example: at the 2004 Michigan competition, my team struggled to install a Walmart tarp to protect the car in the rain. Our paddock neighbors laughed and wondered why they had a school-branded trailer with roll-down canopy and we did not. For a long while, so did we. But one of the above teams won the competition, the other finished 87th. Having a high end trailer with various accoutrements does not substitute for a well-engineered car.

That said, the more FSAE teams can focus on their core activity and not cursing the wind in a Detroit parking lot, the more likely they are to be successful.

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BIOGRAPHICAL INFORMATION

Michael L.W. Jones is Professor and Program Co-ordinator of the Communication, Culture, Information and Technology program at Sheridan College. His primary research interests include the educational impact of engineering student project teams and how such teams navigate organizational development and knowledge management challenges.

Corresponding author

Dr. Michael L.W. Jones
Sheridan College
1430 Trafalgar Road
Oakvile, ON, Canada L6H 2L1
1-905-845-9430 x 5555
michael.jones5@sheridancollege.ca

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AN INTEGRATED PROFESSIONAL PRACTICE AND EMPLOYABILITY INITIATIVE IN AN ENGINEERING UNDERGRADUATE PROGRAM

Simon Howell, Geoffrey Tansley, Graham Jenkins & Wayne Hall

School of Engineering and Built Environment, Griffith University

ABSTRACT

To attain accreditation, Engineering programmes in Australia must meet Engineers Australia's Stage 1 Competency Standards. In addition to the academic criteria, there is an expectation that students meet professional practice requirements. In the School of Engineering and Built Environment at Griffith University, the professional practice requirement is that students "must complete a minimum of 12 weeks (60 days) of approved experience in an engineering practice environment (or a satisfactory alternative) during their degree studies." While there have been several opportunities for scaffolded student-industry interaction in earlier years of the programme, the opportunities were not integrated into the programme, were inconsistent across the disciplines, and not coherently articulated as professional practice and employability opportunities for students. The result was that some students entered the final year of the programme without sufficient industry internship experience, or exposure to industry professionals, or a lack of understanding of professional expectations and practice. The paper discusses the introduction and implementation of an integrated Professional Practice and Employability Skills stream within the programme to improve graduate employability and better support students as they develop into engineering professionals. The paper also describes a method for monitoring and assessing professional practice supported by a reflective ePortfolio.

KEYWORDS

Professional Practice, Employability, Engineering Curriculum, ePortfolio, Standards: 3, 4

INTRODUCTION

For Australian Engineering programmes to be accredited, they must meet Engineers Australia's Stage 1 Competency Standards (Engineers Australia [EA], 2011). These standards group the competencies into three broad areas: knowledge and skill base, engineering application ability, and professional and personal attributes. Griffith University engineering programs and the individual courses are mapped to the EA standards and also to the Griffith Graduate Attributes (Griffith University, 2016). Previous researchers (Campbell, Dawes, Beck & Wallace, 2009; Popp & Levy, 2009) have described mapping the initial version of the CDIO syllabus (Crawley, Malmqvist, Ostlund, & Brodeur, 2007) to the

Australian university context. The revised CDIO standards and syllabus (Crawley, Malmqvist, Östlund, Brodeur, & Edström, 2014) have been useful in framing a 2017 redesign of Griffith Engineering programs to improve graduate outcomes and the overall quality of the programmes. In line with the CDIO call for “a systematic approach to teaching professional engineering skills, also referred to as personal and interpersonal skills” (Crawley et al., 2014, p. 114), this paper will focus on the introduction and implementation of a Professional Practice and Employability Skills (PPES) stream into an undergraduate Engineering programme, and a method for monitoring and assessing professional practice supported by a reflective ePortfolio.

THE NEED FOR CHANGE TO PROFESSIONAL PRACTICE AT GRIFFITH

Griffith University is a multicampus university spread across Brisbane and the Gold Coast with engineering programmes available at the Nathan and Gold Coast campuses. Students can choose to major in Civil, Mechanical, Electrical, Electronic, Environmental, and Software Engineering, with the range of majors varying depending on the campus. In 2018, there were around 1350 undergraduate students enrolled in the School of Engineering and Built Environment.

All Engineering students complete a work placement in their final year as part of the Industry Affiliates Program (IAP). The IAP office has since been renamed the Work Integrated Learning office, but still assists in linking engineering students with suitable projects with different industry partners. Students also take a Professional Practice course (6008ENG IAP - Professional Practice) concurrently with their final year thesis and work placement with an industry partner (6007ENG IAP - Thesis). The thesis is usually linked to the student’s industry placement, with some students doing an internal project when a suitable external project is unable to be sourced. Many students concentrating on their work placement and thesis often struggle to see the relevance of the professional practice course (6008ENG) to their degree and engineering career, as evidenced by some of the following comments from student evaluation forms:

> *It is a useless course that just takes time away from IAP projects. I learnt nothing during the course.*
>
> *It saps a lot of time out of the IAP thesis course which is the more important course.*

In addition to some negative perceptions of the final year professional practice course itself, students sometimes reached the final year of the engineering programme without sufficient industry internship experience, exposure to industry professionals, or a lack of understanding of professional expectations and practice. While there have been several opportunities for scaffolded student-industry interaction in earlier years of the programme, the opportunities were not integrated into the programme, were inconsistent across the disciplines, and not coherently articulated as professional practice and employability opportunities for students. Changes clearly needed to be made.

INTEGRATING PROFESSIONAL PRACTICE AND EMPLOYABILITY SKILLS

In line with section 3 of the EA Stage 1 competencies (EA, 2011), and CDIO Standard 3 requiring integration of professional skills (Crawley et al., 2014), the PPES stream is systematically integrated into the programme across all disciplines to assist students to develop their professional and personal attributes. Table 1 shows some broad similarities between section 3 of the EA Stage 1 competencies and the CDIO Syllabus V2.0. Some EA competencies such as *3.3 Creative, innovative and pro-active demeanour* and *3.4 Professional use and management of information* appear to only match some aspects of the CDIO Syllabus as indicated in the table.

Table 1: EA Standards (Professional and Personal Attributes) and CDIO equivalents

Engineering Stage 1 Competency	CDIO Syllabus v2.0 equivalent
3.1 Ethical conduct and professional accountability.	2.5 Ethics, Equity and Other Responsibilities
3.2. Effective oral and written communication in professional and lay domains.	3.2 Communications
3.3. Creative, innovative and pro-active demeanour	Partial match to 4.7 Leading Endeavours (4.7.1 - 4.7.4)
3.4. Professional use and management of information	Partial match to 2.2 Experimentation, Investigation and Knowledge Discovery (2.2.2)
3.5. Orderly management of self, and professional conduct.	2.4 Attitudes, Thought and Learning
3.6. Effective team membership and team leadership.	3.1 Teamwork

Griffith University has a 12-week trimester system, with the majority of Engineering courses being offered in trimester 1 (T1) and trimester 2 (T2). A number of first year Engineering courses are offered in trimester 3 (T3) for students needing to repeat T1 courses, or for those who commenced in T2. The PPES stream starts in T1 first year, and continues each trimester over the first three years, culminating in the final year Professional Practice capstone course (6008ENG). The aim is for every student to participate in an assessable, integrated component of the PPES stream each trimester over the first 3 years of the program. To ensure this happens, one course each term is designated to be a 'Professional Practice and Employability Skills Partner' (PPESP) course.

The PPES stream elements are part of the assessment schedule for these designated PPESP courses, and will generally be worth a minimum of 10% of the marks for the course. Where practicable, common core courses have been designated as the PPESP courses. When this is not possible, each major has a designated PPESP course. It is worth noting that designating one course each trimester as a PPESP course to be a formal component of the PPES stream does not preclude other courses from including PPES elements. Indeed, all course convenors will be encouraged to include PPES elements, with the PPESP courses ensuring all students have sufficient exposure to Professional Practice to meet the EA Stage 1 Competencies.

The PPES stream is to be one segment of larger intent aimed to ensure that Griffith graduates are job ready, not just in their technical knowledge but in the full range of professional competencies. The overall process involves:

- An industry informed curriculum including engagement in curriculum design directly through the discipline specific Industry Reference Groups and overall through the School Advisory Board, and indirectly by staff-industry interactions; and involvement

in curriculum delivery through guest lectures, material delivery, and industry-based projects;
- Students developing their professional engineering identity through their reflective professional portfolio; and
- Students enhancing their employability through their personal skill development

Three common core courses, 1701ENG Creative Engineering (Year 1, T1), 1022ENG Engineering Design Practice (Year 1, T2), and 3004ENG Project Management Principles (Year 3, T2) are designated as PPESP courses. The final year core course 6008ENG IAP – Professional Practice will act as a professional practice capstone for all majors. This leaves 3 PPESP courses, one in each of Year 2 T1, Year 2 T2 and Year 3 T1, to be designated for each major as shown in Table 2. Where practicable, these are courses that are shared between majors to minimise the number of formally designated PPESP courses.

Table 2. Professional Practice and Employability Skills Partner Courses

Year	Trimester 1	Trimester 2
1	1701ENG Creative Engineering	1022ENG Engineering Design Practice
2	Designated major PPESP course	Designated major PPESP course
3	Designated major PPESP course	3004ENG Project Management Principles
4	6008ENG IAP – Professional Practice	

PPES ACTIVITY OVERVIEW

Table 3 gives an overview of the completed activities at the time of writing, and the following section will describe the PPES activities in more detail.

Table 3: Overview of PPES Courses and Activity Focus

Trimester	PPESP Course	PPES Focus
T1, 2017	1701ENG Creative Engineering	Raise awareness of skills needed in the profession Part of milestones assessment (10%)
T2, 2017	1022ENG Engineering Design Practice	Employability week - assessed site visit and development of CV (20%)
T3, 2017	1701ENG Creative Engineering	Video interview highlighting skills developed through the projects in the course (10%)
T1, 2018	Designated PPESP Courses: Construction Materials Digital Electronics Mechanical Engineering Design Environmental Microbiology and Ecology	Assessed reflection on industry guest speaker presentation. Students will be required to reflect on content of the presentation, and link the guest speaker's comments to the EA Stage 1 Competencies (10%)

Creative Engineering

The first PPESP course, 1701ENG Creative Engineering, is taken by both Engineering and Industrial Design students and is available in trimester 1 and 3. Creative Engineering is a project-learning based course where students are asked to work in teams to design creative solutions for selected problems. This is in line with CDIO standard 4 which requires a core first year course which functions as an introduction to engineering practice and the professional skills required to be successful in the field (Crawley et al., 2014). In trimester 1, 2017, the aim of the PPES assessment item was to highlight the importance of communication skills and teamwork in engineering practice. Engineering students were asked to read and write a reflection on a conference paper by Male, Bush, & Chapman (2009) which highlights the competencies required by engineers graduating in Australia. In a similar manner, Industrial Design students were asked to read and write a reflection on chapter 6 of Design Education and Beyond (Rodgers & Milton, 2011).

The trimester 1, 2017 offering of Creative Engineering was modified version of a course previously taken only by industrial designers. While there was some positive student feedback on the aims of course, the course suffered from a major last-minute staff change prior to the start of the term which impacted on the organisation of the course. There were also some difficulties in meeting the differing needs and expectations of both the engineering and the industrial design students, as well as trying to expose students to open-ended projects with conflicting feedback from teaching staff. The following positive comments from the student evaluation of course forms showed some awareness of the aims of the course:

> *I think the concept behind the course is admirable; that is, a course that encourages engineers and industrial designers to think creatively, critically, and with a whole of systems approach could be quite helpful, if executed properly.*
>
> *It showed many different aspects of design that are very important, rather than just drawing parts for things. It really emphasized elements of marketing that often seem to be ignored by engineers. It encouraged students to actually do research into the target market and their problems. It also encouraged students to imagine having to actually build or use the products we designed.*

Creative Engineering and its PPES assessment item were extensively redesigned for Trimester 3. In the revised PPES assessment item, each student is required to submit a 5 minute video, aimed towards an employer, where students describe the skills they have developed through completing their design project.

Employability Week

A crucial part of the PPES stream implementation led to a major change in the Engineering program structure, with week 7 of Trimester 2 designated as “Professional Practice and Employability Week”. During Employability week, normal teaching activities are suspended for the majority of Engineering courses, and the week is reserved for a program of site visits, industry talks and employability enhancement activities. In previous years, it had been very difficult to hold such activities during normal teaching weeks, or vacations, at times that are suitable for all students.

By embedding a dedicated non-teaching week into the first three years of the programme, time is created for these events, both for activities aligned with the T2 PPESP courses, and for other extracurricular activities. Teaching staff also become available to assist with leading visits. The week will be rolled out through the program year by year, and by 2019, Employability week will be embedded across the first three years of the programme. The introduction of employability week and the loss of a teaching week in the term required first year courses to be redesigned for 2017, and second year courses are currently being redesigned for 2018. There will be a similar impact on third year courses in 2019. Employability week will not require timetable changes in the final year as the majority of the students are off campus for their work placements.

In support of the Employability week initiative, Teaching and Learning Development Funding from the Group Dean (Learning & Teaching) was obtained to trial a Site Visit program at the Gold Coast campus during week 7 of second semester, 2016. During the trial, timetables were unable to be altered and all lectures, tutorials and laboratories had been scheduled as normal. A program of 14 site visits was arranged with local industry and offered initially to first year students. Later year level students were also able to participate where space permitted. Industry feedback was very positive with almost all potential partners offering future site visit opportunities. Given the restrictions imposed on attendance by class timetables, the student response rate was good, with those that participated very enthusiastic about their experience. As a result of the trial response, further funding was obtained and used to purchase protective gear such as hard hats, high visibility vests, and safety glasses for student use, as well as to provide transport to site locations as required. Students visiting construction sites were required to provide their own steel-capped boots. In the longer term, the intention is to obtain funding from industry sources to support employability week activities.

First year students commencing during 2017 were the first to experience Employability week in a T2, 2017 course: 1022ENG Engineering Design Practice, and around 350 students across both campuses were required to visit at least one site. Students could select a site from 15 different partner organisations across the range of majors, with some organisations hosting multiple visits. As part of the course assessment (20%), students were required to do some preliminary research into the site, or organisation responsible for the site, take notes during the visit, write a reflection after the visit, and also submit a CV targeted towards the organisation responsible for the site. Student feedback on the employability week and site visits was positive as in the following comments from student evaluation forms:

> *I found it particularly good when it came to setting the students up to experience how an engineering company works. I loved getting to* [*sic*] *opportunity to do company visits*
>
> *I found the site visit and resume project particularly useful to my career pathway and* [it] *helped me prepare for my future.*

Employability week activities for later years are currently under development, and Table 4 shows examples of proposed activities tailored specifically for each level of the program. Although students from all levels will be able to attend any activity, preference will be given to students from the targeted year level where space is limited.

Table 4. Proposed Employability Week Activities

Year Level	Proposed Targeted Activities
1	Series of general site visits not necessarily related to a particular major Series of guest speakers from industry are planned to talk about possible careers
2	CV building and letters of application to assist students with seeking paid approved engineering work experience, Course specific site visits
3	Course Specific Site visits, IAP preparation program will be offered to help students be “shovel ready” for their IAP project by week 1 of T1, Employment Fair

GRADUATION AND PROFESSIONAL PRACTICE REQUIREMENTS

Coupled with the completing the academic requirements of the BEng(Hons) program, a student must also complete a minimum of 12 weeks (60 days) of approved experience in an engineering practice environment (or a satisfactory alternative) during their degree studies to be able to graduate. The 60 days of approved experience requirement is currently incorporated into a core course in the final year of all engineering programs, 6008ENG IAP – Professional Practice, with the course convenor managing the approval of a student’s professional practice. The satisfactory alternative is interpreted as requiring students to complete a minimum of 60 points of approved professional practice collected as per Table 5.

Table 5. Overview of Professional Practice Categories and Requirements

Category	Professional Practice Description	Points
A	At least 30 points of junior professional or senior para-professional engineering practice within a professional engineering context.	1 point per day of approved work experience
B	No more than 20 points of independent university based engineering research as approved by the course convenor.	1 point per day of approved engineering research
C	No more than 20 points of junior para-professional engineering practice within a professional engineering context.	1 point per day of approved work experience
D	No more than 10 points of work experience outside of an engineering context.	1 point per day of approved work experience
E	No more than 5 points of engineering tutoring and/or teaching within University level courses.	1 point per 3 hours of approved teaching experience. 1 point per 6 hours of approved tutoring/lab demonstration experience
F	No more than 5 points of field trips to engineering related projects.	½ point per approved field trip which includes an assessed report
G	No more than 5 points of attendance at guest lectures by practicing professional engineers.	¼ point per approved guest lecture attended at the University ½ point per approved guest lecture attended at a professional engineering association

At present, the majority of the students are able to complete the 60 days professional practice requirements and graduate on time, although many of the students tend to accumulate the required professional practice points purely from their final year work placement (Category A). There are also small numbers of students each year that are unable to graduate due to not meeting the professional practice requirements. The introduction of the integrated PPES stream aims to address this issue and improve overall employability by exposure to engineering practice throughout the program. Students will also be required to evidence their professional practice by collecting points across a wider range of categories, not just from Category A.

DOCUMENTING PROFESSIONAL PRACTICE

The collection and management of students' professional practice development is not currently handled in a very efficient manner, and as part of the PPES stream rollout, an ePortfolio system will be used to streamline the process for both staff and students. Griffith University has recently selected the PebblePad ePortfolio platform (PebblePad, 2017) for use across the institution, with each student having their own PebblePad account. An advantage of an online portfolio system is that it allows students to collate and curate evidence of their learning experiences as they move through a degree program (Hallam & Creigh, 2010), and it can assist students in connecting their learning with the development of professional skills when appropriately scaffolded (Faulkner, Mahfuzul, Waye, & Smith, 2013).

All the PPES assessment items are required to be submitted and stored in PebblePad so students can monitor their own progress. Many of the other discipline specific courses will also require students to document their learning via their ePortfolios. When the 2017 starting cohort of students reach the capstone 4th year professional practice course in 2020, they will be required to articulate how they have met their professional practice requirements and the EA Stage 1 competencies by submitting evidence and suitable documentation collated throughout the program. This is similar to approaches where engineering students used an online portfolio to evidence progress towards graduate attributes (Palmer, Holt, Hall, & Ferguson, 2011), and Accreditation Board for Engineering and Technology (ABET) outcomes in the United States (Christy & Lima, 1998; Heinricher et al., 2002; Williams, 2002).

CONCLUSION

The CDIO standards are important in shaping the learning and teaching experience offered to our students. In addition, the implementation of an integrated Professional Practice and Employability Skills stream aims to ensure that Griffith Engineering graduates have a strong understanding of engineering practice, and are ready to perform to the best of their ability when they move into industry. Future research will be needed to evaluate the success of the initiative, and to monitor the students' development of professional and personal attributes as they reflect on their progression towards becoming engineering professionals.

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BIOGRAPHICAL INFORMATION

Simon Howell is the First Year Coordinator on the Gold Coast campus in the School of Engineering & Built Environment at Griffith University, Australia. He was previously a Student Success Advisor and has a background in student support, academic skills development and curriculum design. He is part of the teaching team for two core first year courses: Creative Engineering and Engineering Design Practice. Simon is particularly interested in curriculum renewal, project-based learning, and improving the development of professional skills in engineering programs.

Geoffrey Tansley is currently Professor of Engineering Design having just completed a five-year period as Head of School of Engineering & Built Environment at Griffith University, Australia. Geoff's previous engagements include: Professor and Head of Mechanical Engineering and Design at Aston University, UK, Associate Professor in Mechanical Engineering at Nottingham University, UK, Chief Mechanical Engineer at VentrAssist, Australia, Senior Lecturer in Biomedical Engineering at Flinders University of South Australia and Lecturer in Mechanical Engineering at Adelaide University, Australia. Geoff teaches in the areas of Design and Fluid Mechanics, and researches and consults widely in the design of cardiac medical devices.

Graham Jenkins is an engineer with over 10 years of experience in the water engineering industry and 25 years of academic experience. He was previously the Deputy Head (Learning and Teaching) in the Griffith School of Engineering & Built Environment, and was the academic lead in the Industry Affiliates Program. Graham developed the program to give students in Griffith Sciences the opportunity to undertake industry-based research as part of their degree studies. This has allowed students, industry and academia to form unique partnerships to move students into the workplace through a structured approach to work integrated learning. Graham currently teaches Creative Engineering and a humanitarian design elective focusing on providing sustainable water resources in developing countries.

Wayne Hall holds a PhD from the University of Warwick and a PGCert in Learning and Teaching from the University of Plymouth. He is a Corporate Member of the Institution of Mechanical Engineers (MIMechE) and a Chartered Engineer (CEng). He is currently Deputy Head (Learning and Teaching) in the School of Engineering and Built Environment at Griffith University. Wayne's research interests lie in the design and manufacture of lightweight and Fibre Reinforced Plastics (FRPs) and in engineering education related research. His interest in engineering education is focused on the development and implementation of successful teaching and learning strategies for on- and off-campus (distance education) students, and on the implementation of Project-Based Learning (PBL) in the engineering curriculum.

Corresponding author

Simon Howell
School of Engineering and Built Environment
Griffith University, Gold Coast Campus
Parklands Drive
Southport QLD 4215
Australia
+61 (07) 555 29341
s.howell@griffith.edu.au

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A PRACTICAL APPLICATION OF BUSINESS SYSTEM IN ENPIT2

Satoru Myojin 1, Masahiro Sakai 2, Naohiko Hayata 3, Mitsutaka Yasuda 4, Takeshi Tanigawa 5

1,5, Department of Business
and Information Systems, Hokkaido Information University, Japan
2, Department of Medical
Management and Informatics, Hokkaido Information University, Japan
3, 4, Department of
Information Media, Hokkaido Information University, Japan

Kei Ito 6, Michiko Oba 7

6,7, School of Systems Information Science, Future University Hakodate, Japan

ABSTRACT

The Education Network for Practical Information Technologies (enPiT) is a nationwide cooperative effort between multiple universities and industries, under the auspices of the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT). Its goal is to develop human resources capable of utilizing state-of-the-art information technology in a practical way. Throughout the latter half of 2017, Hokkaido Information University (HIU) participated in succeeding activities in enPiT for undergraduate students (enPiT2). This activity program focuses on the business-system-design field. In this program, Project-Based Learning (PBL) as CDI of CDIO is used for learning style, including a "service design" workshop in collaboration with each university student after a preliminary study of the introductory human interface and web programming (PHP). Following the workshop, students participated in facilitation and user-centered design seminars, and later conducted PBL in groups at each university campus. Collaborative learning was seen to boost student motivation significantly. The process and results of growing was seen greatly by receiving excitement while mutually collaborating each other. These contents and results are reported.

KEYWORDS

Business system design, service design, active learning, PBL, CDIO Standard: 5, 8

INTRODUCTION

There is an ongoing need for problem-solving skills in modern Japanese society. Particularly with the rapid advance of technology, the ability to incorporate information technology into solutions is indispensable. Training human resources capable of solving specific problems through the use of IT is extremely important.

1.enPiT

In order to foster such human resources, the "Project to formulate a practical education network for training information technology human resources at the Ministry of Education, Culture, Sports, Science and Technology" was initiated in Fiscal Year 2012. This project is a nationwide network of multiple universities and industries, and is a publicly offered project aimed at implementing and disseminating practical education, such as problem-solving training based on actual tasks. As a result of the public invitation, a "Collaborative network for practical information education beyond areas and areas" (application representative school: Osaka University) was adopted.

enPiT has four fields: cloud computing, security, embedded systems, and business applications. It is oriented toward graduate school master's course students to promote a wide range of knowledge in each field. Teachers and engineers from each field gathered from 15 collaborating universities and companies across Japan (Figure 1).

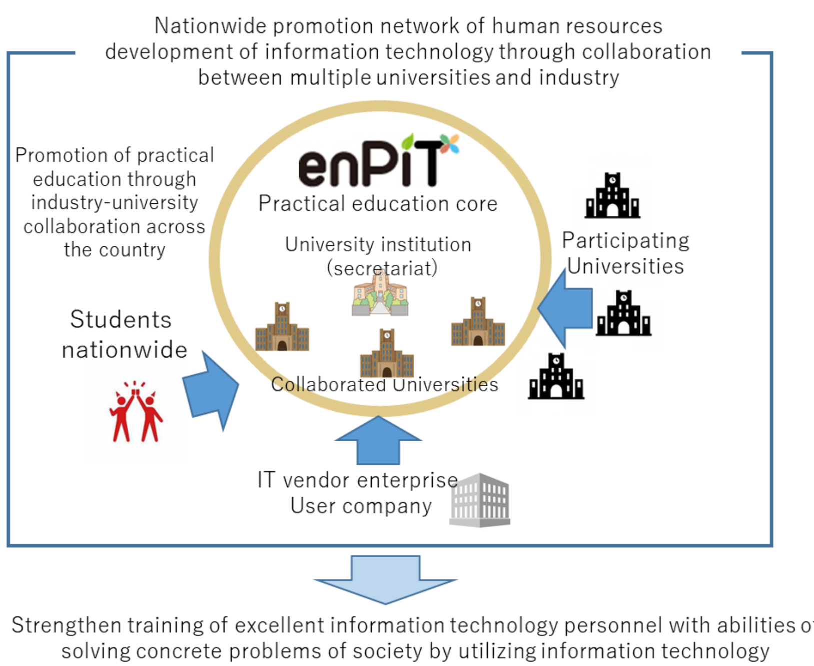


Figure 1. enPiT Structure

In enPiT, practical education is conducted in each field based on the Educational Program Framework, as shown in Figure 2 and detailed below.

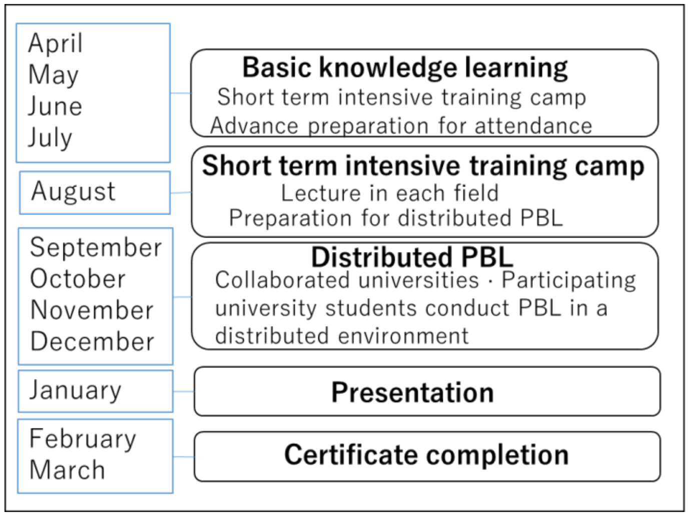


Figure 2. Educational Program Framework

1.1 Basic knowledge learning

The first phase includes learning basic knowledge necessary for implementation of short term intensive training camps and distributed PBL. Lectures from cooperating universities are offered, and teaching materials from any of the fields may be used. Different in each field, specifically, for example, software engineering, software development, prototype programming, human interface, information system security operation literacy, etc.

1.2 Short-term intensive training camp

This phase involves intensive education for about 1 week, including lectures and exercises related to each field of technology (other than basic knowledge, state-of-the-art technology etc.). This phase is preparation for PBL. Concretely, for example, practical distributed application development, practice exercise (security attack/ defense exercise /hardware security exercises/ incident correspondence exercises), robot competition, business service design workshops, etc.

1.3 Distributed PBL

PBL is implemented under the distributed environment for each field. Results are given in presentations following this phase. For example, cloud development project/ cloud service development, advanced integrated learning that reinforces practical skills and acquires applied skills, OJL (On the Job Learning), embedded system development general exercise, business service design/ prototype development, etc.

1.4 Results of enPiT

There were 305 graduates in FY2013, but in FY2016 that number jumped to 496 people. In the space of 4 years, a total of 1,742 people completed the program. In addition to the core 15 universities, the number of participating universities increased to 105, and supporting companies to 133.

2. enPiT2

Meanwhile, in FY2016 MEXT announced the "Formation of training center for information technology personnel supporting growth fields". This is a practical information technology education program that focuses mainly on undergraduate departments. This new program was named enPiT2, then original project for graduate students (enPiT) was renamed to enPiT1. Utilizing the findings of the program of enPiT1 so far, practical learning of state-of-the-art technology in the four areas of "big data/ AI", "security", "embedded systems", and "business system design" is conducted via PBL with the aim of acquiring the fundamentals of social success such as communication skills and leadership.

enPiT2 has garnered the cooperation of more than 30 universities across Japan. During FY2016 pilot-tests were done in several ways, and from FY2017 the program was officially implemented. Many undergraduates are participating (Figure 3).

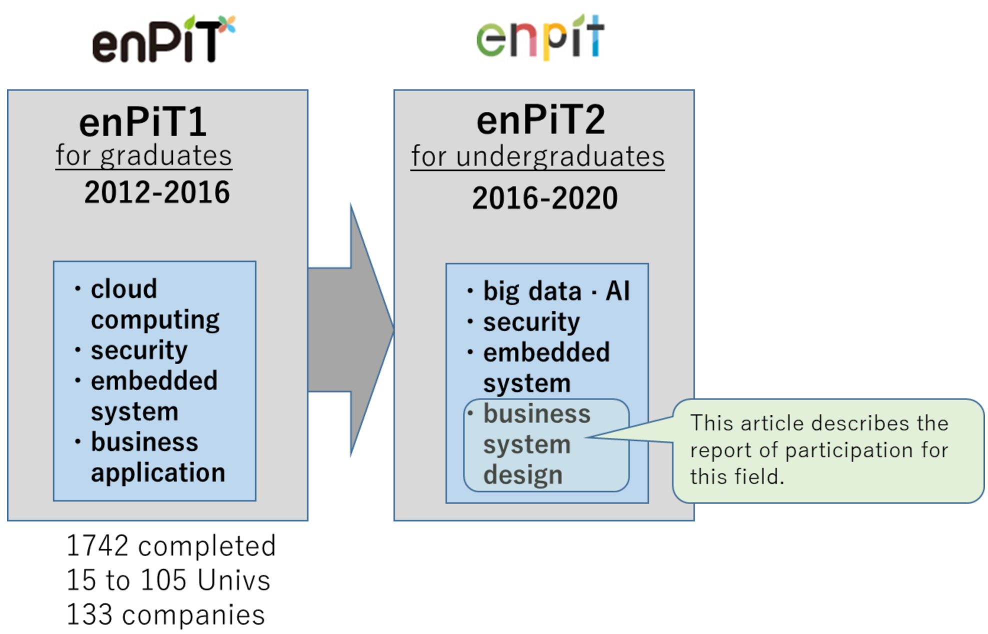


Figure 3. enPiT1 and enPiT2

Since 2017, Hokkaido Information University is working in tandem with Future University Hakodate, one of the collaborated universities in enPiT2.

The following describes our involvement with enPiT2 "business system design" during FY2017 and its relation to CDIO standards.

BUSINESS SYSTEM DESIGN PROGRAM

The enPiT2's business system design field (referred to as BizSysD) aims to develop human resources who can propose and develop their own business applications and system designs as practical solutions to the needs of society and business, and to meet the potential demands of customers. The aim is to nurture innovative human resources who can voluntarily solve practical problems. This program is to develop human resources coping with the innovation in IoT era utilizing ICT business application/ system.

PRACTICE REPORT ON BUSINESS SYSTEM DESIGN

From Hokkaido Information University, 3 students from the Department of Business and Information Systems, Department of Systems and Informatics, and Department of Medical Management and Informatics, and 6 students from the Department of Information Media (total 9) conducted enPiT2 activities described below from July to December 2017.

Basic knowledge learning

As a preliminary study, PHP basics were held from July 21 to August 11 as an introductory topic for web programming for inexperienced programmers. In addition, from July 7 to August 3 we had a human interface lecture and paper prototyping exercise to experience the screen design of smartphones.

Service Design summer camp

A "Service Design" summer camp was conducted at Future University Hakodate for 5 days from August 14 to 18. A total of 25 people, 14 from Future University Hakodate, 9 from HIU, 2 from Kanagawa Institute of Technology students, participated (Figure 4).

We invited lectures from Wide Book Co., Ltd., Cookpad Co., Ltd., DCM Homac Co., Ltd., and provided lectures and practical training on formulating new business models.

The first day featured lectures and group exercises on ideas and leadership. On the second day, there was a lecture on "Service development that successfully attaches to uncertainty" from Cookpad Corporation, and there was an explanation about service development, business model, user first, etc. After that, a panel discussion based on questions from the students was held to further understand the technical aspects of service development and how to proceed with service development.

From the afternoon of the 2nd day until the morning of the 4th day, we held a new business planning exercise with the theme of "making tourism revenue of Hakodate 1.5 times in 2020". We learned about specific idea making, expression, innovation, the business model canvas, and conducted group exercises and presentations. On the afternoon of the fourth day, DCM Homac Co., Ltd. gave a lecture titled "Business Strategy of DCM Holdings, DCM Homacs" on the points of growth of home centers, business strategies and corporate social responsibility.

On the fifth day, students finished their service proposal, learned how to summarize the proposal and how to present it, and then each team gave presentations. As a result of the evaluation by the faculty, Team 5, which proposed Custom Journey, received the Best Award (Table 1. Best Service Design Award).

Teachers from collaborating universities and participating universities and lecturers from companies promoted team formation. During the summer school of service design session, students learned about the design process [CDIO 4.4.1], the design method [4.4.3], and made presentations of the realization method from the design of their ideas [3.2].

Table 1. Team Themes and Awards

team	Short term intensive training camp To make Hakodate Tourism Revenue 1.5 times	
1	Effective Utilization of Hokkaido Tram	Presentation award
2	Squid robot city guide	Idea award
3	MTB rental business	Technical award
4	Hakodate Premium Passport	Business plan award
5	Custom Journey	Best Service Design Award

Figure 4. a: Participants. b: Idea drawing. c: Presentation.

User centered design (UCD)

On August 22 to 24, at HIU, "Mini UCD" was held by Future University Hakodate for 9 students. A lecturer from Osaka University of the Arts was invited and held a SF movies workshop. On the first day, after students watched a SF movie (Star Trek) while sketching with all the students, they understood the worldview of the movie by. They made ideas for the characters in that world and the services and tools that people want to use (Figure 5).

On the second day, they actualized the idea as a real scale prototype and revised it repeatedly while evaluating it experimentally. On the third day, students gave presentations using posters and prototypes, and acted out how to use the prototypes with short skits. At the very end a Q and A session was held between the faculty and students of HIU and Future University Hakodate. This SF workshop created intriguing ideas [CDIO 4.7].

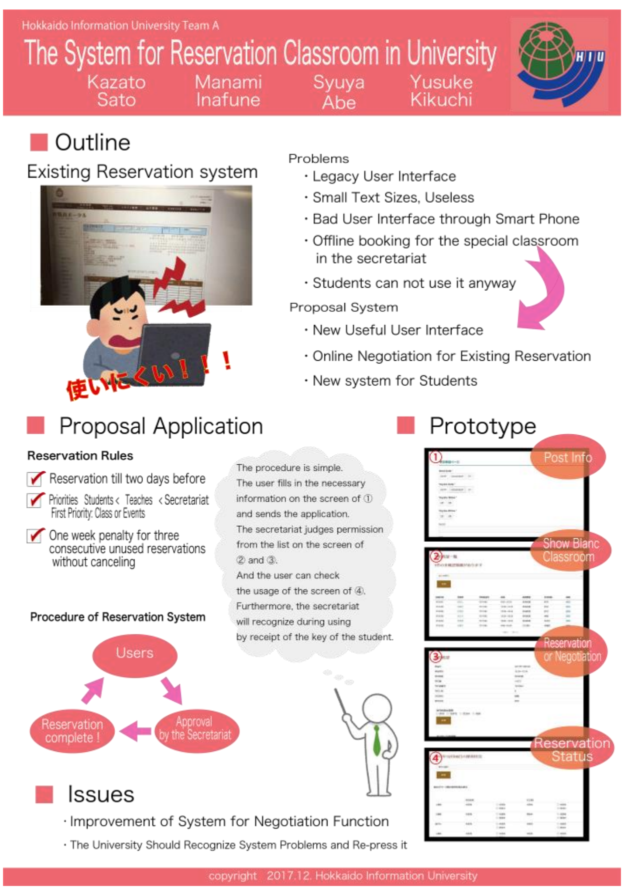
Figure 5. a: SF workshop. b: Private barrier. c: Instantaneous excrement transfer

Facilitation

The ability of leaders to facilitate and encourage participation by students in PBL and to make collaboration successful by members is important. This is an ability that not only leaders but all participants should have. A total of 21 people including 8 enPiT2 participants, 5 other students, and 8 faculty members, participated in HIU session on September 19. This facilitation exercise (how to make meeting/ speak/ listen) was conducted by inviting an external lecturer so that the following PBL to be carried out smoothly.

Distributed PBL

From September to December, on Friday 6 period, we conducted PBL while talking with Future University Hakodate using a video conference system. There were two teams from HIU: Team A's theme was "University Classroom Reservation System" (Figure 6), and Team B's was " Web service for Credibility Judgment of Medical Information from Web" (Figure 7). While doing discussions with teachers and students at Future University Hakodate, the students created and implemented prototypes. The prototype development environment was "PHP and CakePHP" for Team A, and "HTML, CSS and Python" for Team B. In the service design summer camp and this PBL group work, problem definition and solution [CDIO 2.1], gradual preparation by student groups to plan the project was carried out [CDIO 2.4.7, 4.3.4]. Students also experienced remote communication and team work [CDIO 3. 1, 3.2].



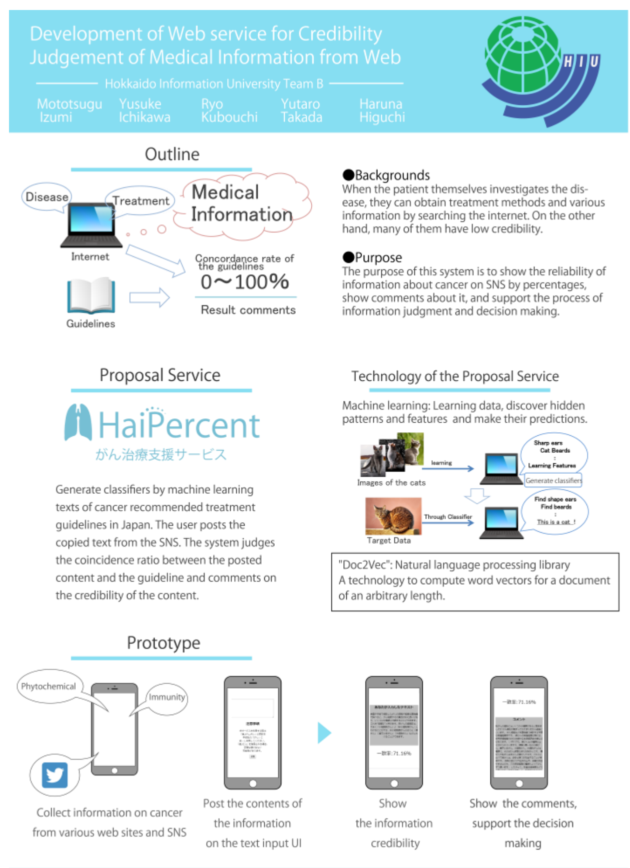


Figure 6. Team A Classroom Reservation   Figure 7. Team B Medical information Review

Result report meeting (at Future University Hakodate)

On December 8 and 9, students gave presentations with posters at Future University Hakodate (Figure 8). It seems that other students and the general public have heard about this, and the students who presented also gained satisfaction and achievement. The announcement on the 9th was a joint presentation in Hokkaido and Tohoku districts at locations such as Muroran Institute of Technology, Iwate Prefectural University, and the University of Aizu. It was evaluated from the viewpoints of ideas, technology, processes, deliverables, and posters, and the students at HIU got a relatively good evaluation.

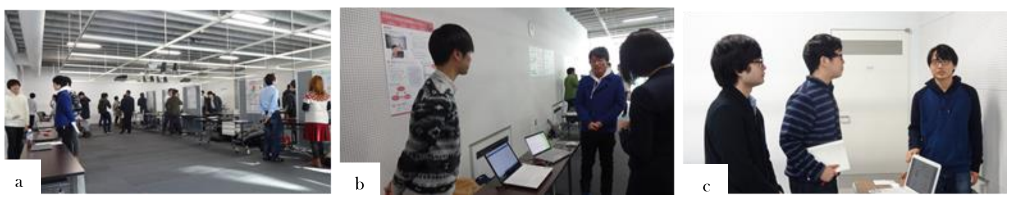


Figure 8. a: Presentation venue. b: Team A. c:Team B

CONCLUSION & FUTURE WORK

The participating students had a good opportunity to realize their ability by discussing and presenting other university students. It seems that the students who participated generally also gained confidence (Table 2). We also confirmed that our students can effectively participate in country-wide efforts. Prior evaluation was carried out with PROG, an evaluation test of generic skills which is carried out as a standard in enPiT. A variety of students made achievements in interpersonal foundation ability, self-fundamental ability, and task assignment fundamentals. The post-PROG test revealed that the human ability of the students such as problem handling capability, communication skill and self-control ability was improved. This collaborative project with universities represents the adoption of CDIO in a scenario where students receive opportunities to improve various teamwork, and project management skills. Students experience conceive-design-implement-operation through a series of activities. As well as opportunities to improve interpersonal skills, self-management, problem-solving skills etc. [CDIO Syllabus 2.4]

The tasks highlight the necessity of having initiatives early in the process and how to proceed with projects such, as reflecting on service designs learned in the first half of the second half of PBL. As a remedial measure, it is conceivable that HIU could practice digital business development methodology focusing on customer value and profitability check through simulation of business model canvas using system dynamics (Figure 9). We would like to work on enPiT2 as a participating school of Future University Hakodate next year also, in order to improve these objectives.

Table 2. Post Impressions of Participating Students

Post Impressions of Participating Students	
Keep New experience and learning (business idea, idea creation method, prototype development, facilitation, joint development of Web services, exchange with other departments and other universities, opinions gained by diverse people, business model, concept thinking, project management, service design, group work), stimulation and growth	**Try** Continue to learn what learned(technical issues and communication methods, practical methods) for future practice and try to master practical skills and business thinking
Problem Inadequate completion of production, separation of practice at the late PBL of summer school acquisition technique, part of separation of lecture (BPM, UCD, ticket development) and workshop (late PBL)	

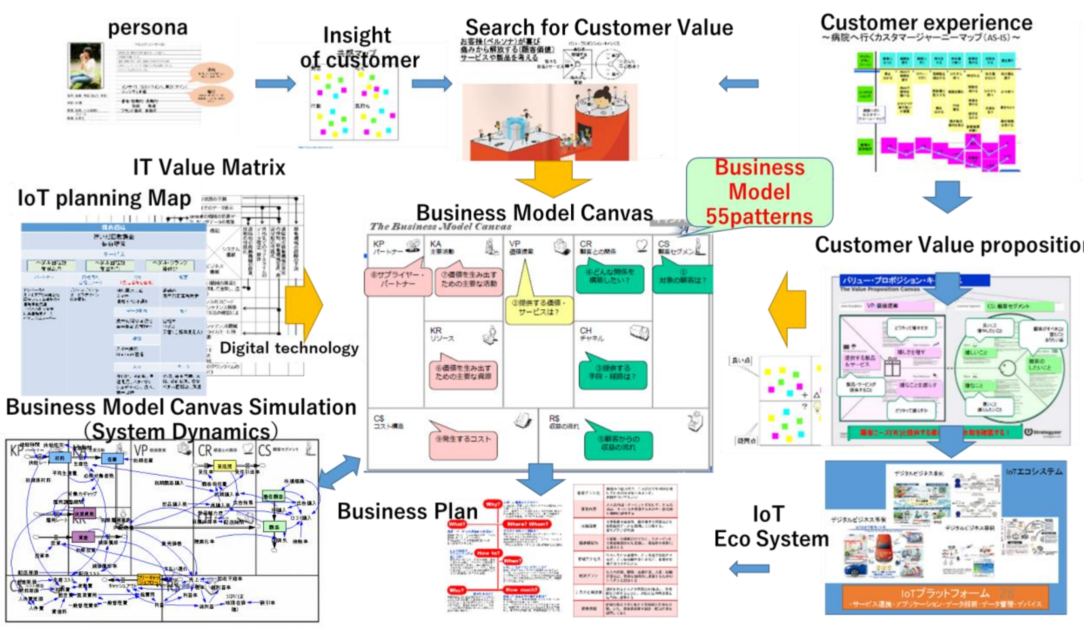


Figure 9. Digital Business development methodology

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BIOGRAPHICAL INFORMATION

Satoru Myojin is a Professor in Digital Business and Chair of the Department of Business and Information Systems at Hokkaido Information University, Hokkaido, Japan. His current research focuses on digital business development methodology and incubation platforms for healthcare services.

Kei Ito, Ph. D., is an associate professor in the School of Systems and Information Science at the Future University Hakodate. His current research focuses on software engineering and on systems for supporting education such as programing education and project-based learning with system development.

Masahiro Sakai, Ph. D., is an associate professor in the Faculty of Medical Informatics at the Hokkaido Information University. His current research focuses on media technology, medical application systems and support systems for Cognitive Behavior Therapy (computerized CBT systems).

***Naohiko Hayata**,* Ph.D., is currently a professor in the Department of Information Media, Hokkaido Information University, Japan. He is engaged in the enPiT2 program at Hokkaido Information University. His academic field is Environment-Behavior Studies. His researches focus on active learning and freshman education in the era of popularization of university education, and community design for super aged societies.

***Mitsutaka Yasuda**,* MBA and MSIT, is a professor in the Department of Information Media, and Director of the Media Creative Center (MCC), at Hokkaido Information University. His current research is pedagogy for practical education in digital content and design industries. He collaborates with Oulu University of Applied Science in Finland in the area of Nordic pedagogies for entrepreneurship in the aforementioned industries.

***Takeshi Tanigawa**,* Ph.D., is a professor in the Faculty of Business Administration and Information Science at Hokkaido Information University. His current research focuses on systems development for education.

***Michiko Oba**,* Ph. D., is a professor in the School of Systems and Information Science at the Future University Hakodate. Her current research focuses on software engineering, documentation systems and support systems for project-based learning with system development.

Corresponding Author

Professor Satoru Myojin
Hokkaido Information University
59-2 Nishi-Nopporo, Ebetsu, Hokkaido,
Japan 069-8585
+81-11-385-4411
myojin@do-johodai.ac.jp

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THE EVALUATION METHOD OF ABILITY ACHIEVEMENT LEVELS IN A CDIO SYSLLABUS

Hua Shen, Fei Gao, Long Liu, Ernan Ju, Xue Han

Department of Electronic Engineering, Dalian Neusoft University of Information, China

ABSTRACT

As engineering education has continued to improve, more colleges and universities have adopted the CDIO engineering education model for the development of course majors and project design， which has improved the engineering skills of their students. However, there are few reports in the literature of the research and development of methods used to evaluate the levels of skills achievement in engineering. Measurement of the effectiveness and achievement of an engineering education can be determined by a scientific evaluation using the engineering education reform. Therefore, determining the best method for guiding the evaluation of teaching techniques and exploring methods for evaluating levels of engineering ability are of very significant in understanding and implementing CDIO education and teaching reform.

In our CDIO syllabus the capabilities of engineering students can be classified into four categories, basic engineering knowledge, personal ability, teamwork and engineering system capability. In this reported study, an artificial intelligent model car project was used as an example to demonstrate how these engineering capabilities are achieved during the process of principle analysis, abstract modeling, plan design, intelligent car platform construction, debugging and operation among others. Measurement standards and scoring systems were established for each stage of the practice process. The evaluation methods were operational and quantifiable throughout the entire practice process and they ultimately ensured an overall improvement in the outcome of the practice of engineering design.

KEYWORDS

Evaluation methods, Ability achievement levels, Intelligent model car project, CDIO syllabus, Standards: 2, 7, 11

INTRODUCTION

The CDIO engineering education mode emphasizes a project-oriented and task-driven education, in which students can acquire the necessary knowledge and skills to complete their tasks and enhance their comprehension and innovation in solving practical problems. Establishment of a CDIO-based learning assessment system can assist in the analysis and evaluation of the students' achievements, and encourage the students' enthusiasm for learning during the entire process of a project design. In addition the assessment system also helps to summarize the experience and discover the problems in the links of teaching and learning to instruct teachers to better fulfill teaching responsibilities in the next teaching process.

There are several evaluations methods that can be used to assess technical projects and design-build-test experiences. In the area of program evaluation, Kaplan *et al*. described an approach called the Balanced Scorecard [1], which includes baseline interviews, and longitudinal studies to assess student learning during project practice. Balanced Scorecards were used to display the status of a program together with a range of techniques for project evaluation. Spady *et al*. first proposed a new idea for educational reform, called Outcome-Based Education (OBE) that consisted of "student centered" teaching concepts to evaluate the curriculum and the effects of teaching [2]. MIT evaluated engineering educational programs using the Accreditation Board for Engineering and Technology (ABET) EC 2000 [3]. Furthermore, OBE has also been used to establish engineering education accreditation standards by ABET [4]. In addition, Vijayalakshmi M. *et al.* [5] used evaluation criteria and a matrix to establish an evaluation of the learning requirements of teaching performance based on the results of a course of study.

Dalian Neusoft University of Information (DNUI) is one of the Chinese universities that has pioneered the CDIO engineering education reform, and as such has developed a TOPCARES-CDIO (T-C) educational model that was adopted from the CDIO international engineering education initiatives. The acronym describes the first-level of eight skill standards for measuring capability. In essence, TOPCARES means Technical knowledge and reasoning, Open minded and innovation, Personal and professional skills, Communication and teamwork, Attitude and manner, Responsibility, Ethical values and Social value created by application practice. Using these 8 first-level skill standards, 32 second-level and 110 third-level skill standards were developed. Over the past several years, continuous effort has been made by DNUI to realize the vision of the CDIO reform.

In this reported study, an intelligent car project for students in the electronic information engineering major was used as a model to evaluate the TOPCARES system through a combination of the knowledge of an electronic information system, personal ability, teamwork and the construction of the intelligent model car. To accomplish this, first, the TOPCARES-CDIO skill standards for the intelligent car project were established using the training objectives of the study major. Then, using an intelligent car system theory analysis, abstract modeling, program design, intelligent car platform construction process, commissioning and other practical processes, four steps that included Conception— Design— Implementation— Operation, were used as skill assessment standards. Finally, a result-oriented analysis of the ability to achieve a select degree of accomplishment that corresponded to a standard practice was established. A two-way system of teaching and learning was achieved by the construction of a closed-loop system for four learning process aspects, which included learning objectives- practice process- results assessment– skill achievement. The effectiveness of instruction teaching was continuously improved, which improved the quality of the students.

LEARNING OUTCOMES AND SKILLS TRAINING OF THE INTELLIGENT CAR PROJECT

The training objectives of the engineering curriculum have been established so that the students can master the basic theory of electronics technology and information systems, which will enable him/her to design and develop electronic products and embedded software. In addition, this course of study will also impart the ability to analyze and resolve complex technical engineering issues. Based on the requirements of the curriculum training objectives, an intelligent car project was established in the second semester of the sophomore year in the electronic information engineering major. This project plays an important role in summarizing and improving the students' previous course work. During the first year of college, students must complete the basic courses of electronic circuits, C language programming and an electrical technology practice project. They must also master the basic knowledge of the course of study, and possess circuit design and software programming skills. In the first semester of the sophomore year, students learn microcontroller theory and application courses, master the knowledge of the Micro Control Unit (MCU) principles, and must understand embedded software development.

The intelligent car practice project is designed to train students how to apply their knowledge of circuit design, embedded development and software programming that they have learned in previous course work. In this project, the students must employ the Altium Designer the industrial EDA tool to design the electronic circuits, C language to program the microprocessor, and the Keil MDK the software programming platform to complete the system requirements analysis, system design, system implementation, system integration, debugging and testing. This latter requirement must be done according to the basic project development flow on the hardware platform and model car which is designed and developed as part of the study major. Students must purchase their own components and tools, and then fabricate a smart car that can track, speed test and perform wireless communication, as shown in Figure 1.

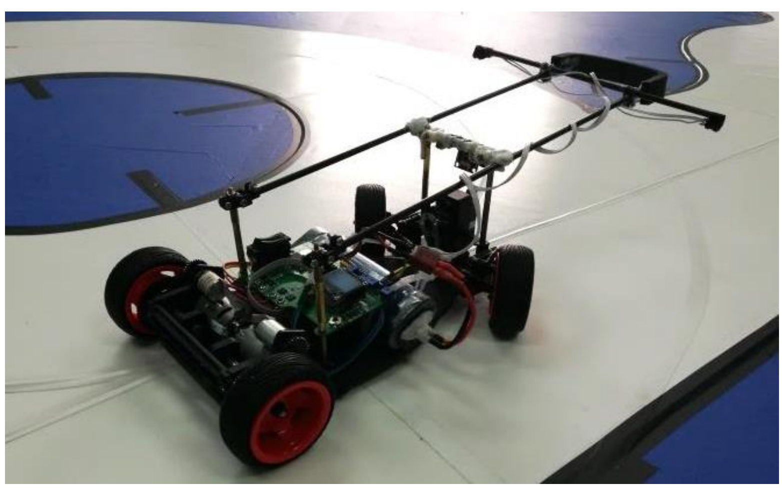

Figure 1. Photo of intelligent car

The intelligent car is composed primarily of a power module, driver module, tracking module, communication module and main control module, the typical design of each functional module is shown in Table 1. Multi-disciplinary technologies are combined in the intelligent car, including intelligent sensing and detection technology, motor control technology, mechanical engineering technology and wireless communication technology.

Table 1. Intelligent car system functional structure and typical design

Module Name	**Typical Design**	**Notes**
Main Control Module	Microcontroller	1. Each functional module circuit designed by students. 2. The typical design in this table is for student's reference. 3. Students can also propose other designs in the development of their intelligent car.
Power Module	Switching Mode Power Supply(SMPS)	
	Low Dropout Voltage Regulators(LDO)	
Driver Module	H-Bridge	
	Metal-Oxide-Semiconductor Field Effect Transistor (MOSFET)	
	Integrated Circuit driver chip	
Tracking Module	Electro-Optical Sensor	
	Electromagnetic sensor	
	Camera	
Communication Module	Bluetooth	
	ZigBee	
	2.4GHz	
	LoRa	

Based on the major training objectives and industrial product design and development process, the teaching goals of the intelligent car project are defined so that the student will master the required professional knowledge and proficiently apply this to the MCU system design and other projects. This will improve the students' practical ability and help them to apply their acquired skills to problem solving, and it will cultivate the students' technical writing capability by writing project documents. The teaching objectives of this project can be summarized into four levels: teaching of electronic information, training students' technical abilities, development of teamwork and intelligent car system construction. The T-C skill standards that are taught in this project are determined by a combination of the T-C syllabus and the teaching objectives of this project, as shown in Table 2.

The development process of intelligent car practice project was divided into four stages that included, Conception, Design, Implementation and Operation, which are executed with the guidance of the CDIO education concept. These stages cover the general development process of electronic products as shown in Figure 2.

Table 2. Three level T-C skill training standards in the intelligent car project

Project Teaching Objectives	Project T-C skill Training Standards (1st-Level Index)	Project T-C skill Training Standards (2nd-Level Index)	Project T-C skill Training Standards (3rd-Level Index)	Description	Weight
Knowledge of Electronic Information	1 Technical knowledge and reasoning	1.2 Core engineering fundamental knowledge	1.2.1 Professional fundamental knowledge	Basic concepts, laws and calculation methods of electrical engineering; basic principles, analysis and design methods of analog circuits; basic principle and analysis and design methods of digital circuits.	4%
			1.3.1 Professional knowledge	Embedded software programming knowledge, hardware design and development methods of electronic product, and PCB layout, PCB processing, welding and debugging methods	10%
Personal technical skills	2 Open thinking and innovation	2.4 Innovation skills	2.4.1 Introduction, digestion, absorption and re-innovation	Adapting to the needs of social development, you should be aware of continuous innovation and development, and be ability to study alone, developing and researching new technology. Referring to the method introduced and according to the actual needs use the advanced EDA tools to solve the problems during design and test of complex embedded systems.	5%
	3 Personal and professional skills	3.1 Analytic reasoning and problem solving	3.1.1 Problem Identification and Formulation	Define system performance metrics, based on customer needs. Propose and describe engineering problems that need to be solved. In a timely manner, identify the problems in design, welding and debugging.	8%

Project Teaching Objectives	Project T-C skill Training Standards (1st-Level Index)	Project T-C skill Training Standards (2nd-Level Index)	Project T-C skill Training Standards (3rd-Level Index)	Description	Weight
	4 Communication and teamwork	4.1Communication skills	4.1.3 Written Communication	Compose technical documents, project reports (including charts)	3%
		4.2 Skills for communications in foreign languages	4.2.2 Reading and understanding professional literatures	Read and understand the literature in the field, and be capable of using the English version of the development tools	5%
	5 Attitude and manner	5.1 Personal attitude and habits	5.1.2 Learning attitude and habits	Develop a good learning attitude and learning habits	5%
Teamwork skills	4 Communication and teamwork	4.3 Teamwork	4.3.1 Forming Effective Teams	Be able to establish form teams, and complete project collaboratively	5%
System building skills	8 Social contribution by application practice	8.6 Conceiving system engineering and management	8.6.1 Understanding Needs and Setting Goals	Define system performance metrics and system goals and requirements, based on function requirements	5%
		8.8 Implementation	8.8.1 Designing a Sustainable Implementation Process	Design the software and hardware development plan of the car project, implement this plan, draw the hardware circuit schematic and complete the embedded software programming work.	10%
			8.8.2 Hardware Manufacturing Process	Draw circuit schematic, and PCB to produce the intelligent car control.	10%

Project Teaching Objectives	Project T-C skill Training Standards (1st-Level Index)	Project T-C skill Training Standards (2nd-Level Index)	Project T-C skill Training Standards (3rd-Level Index)	Description	Weight
			8.8.3 Software Implementing Process	Based on to the requirements of the system design, complete the design and implementation of the software system using the advanced programming language and algorithm. Write the main program, the photoelectric sensor collection, the motor drive code, implement these with the hardware to obtain the complete system.	10%
			8.8.4 Hardware Software Integration	Integrate an implement the software and hardware.	5%
			8.8.5 Test, Verification, Validation and Certification	Based on to the design requirements of the system, test the functions of the software and hardware in the system and verify using scientific verification and testing methods.	15%
Total					100%

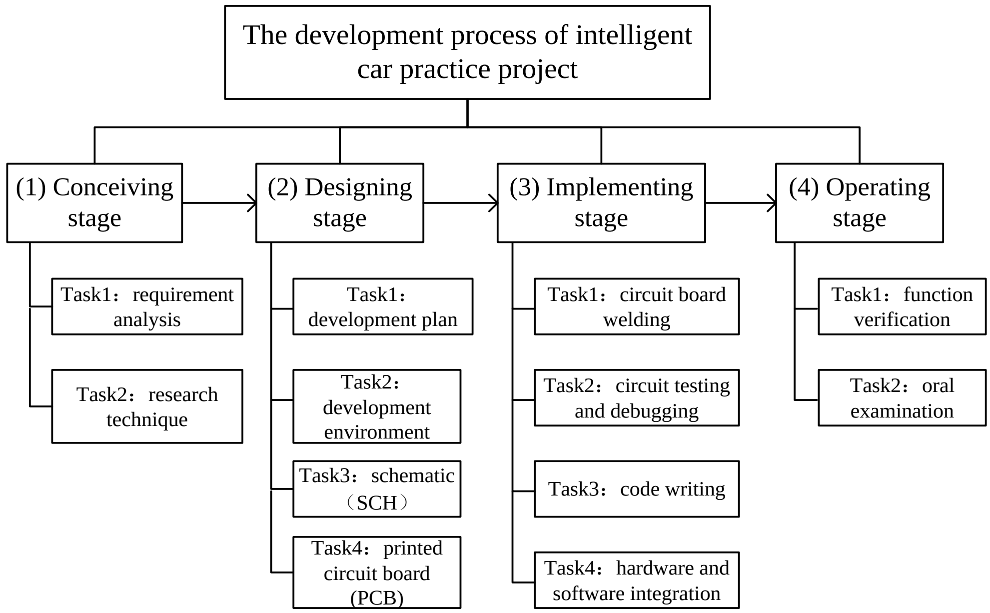

Figure 2. The development process of intelligent car practice project

Conceiving stage

In this stage of the project the student must analyze the intelligent car system, research technical information, read the documents of the professional field, propose the technical features and design requirements for the intelligent car system, and write a technical report.

Designing stage

In the design stage, the student must design the overall plan of the intelligent car based on the results of the concept stage, and using the requirement analysis, the circuit principles and the micro-controller working principles must be articulated and a functional block diagram of the system must be drawn.

Implementing stage

Here the student will draw the schematic circuit diagram based on the function module of the intelligent car system, and complete the PCB design and wiring work and build the embedded operation system on the embedded system development platform. The student must also complete the software functional design using modular software programming ideas and methods, and the sensor detection, motor and servo control algorithms. A software flow chart is then constructed of each function module. The software code is written and the program is downloaded to the microcontroller.

Operating stage

In this stage the student completes the circuit board welding, makes and assembles the car. In addition the student designs a program to test and debug the system and verify its function.

DESIGN SKILL ASSESSMENT METHOD FOR THE INTELLIGENT CAR PRACTICE PROJECT

The evaluation of students' learning outcomes is used to measure the achievement of the expected learning goals for each student, which is an important part of teaching. The evaluation of the students' skills should be planned and implemented based on the expected learning outcomes of the project. The intelligent car practice project focuses on the cultivation of students' skills and the assessment of this process is combined with the major training objectives of the T-C syllabus. To reform the teaching process by changing from a single learning assessment, a new, dynamic learning assessment method has been gradually established to adapt to the needs for training senior personnel.

The intelligent car practice project was used to assess the four stages of the project development, and develop detailed examination and scoring standards. We assessed the weight of the expected standards' value according to the importance of the students' skills, and the process for this specific assessment and scoring standards are shown in Table 3. The evaluation process and the skill assessment method of the four project stages are introduced in the steps below combined with the T-C teaching model. Student achievement is divided into five levels (1 = Poor, 2 = Pass, 3 = Middle, 4 = Good, 5 = Excellent).

Step1: Conceiving stage

In the concept stage, the students are required to analyze the requirements of the project, identify the problems and their solutions. The students must apply their basic engineering knowledge to analyze the relevant circuit principles of the project, search the technical chip datasheets and related professional technical documents of the project, write technical reports using professional terms, discuss system requirements, and produce written communications. Therefore, in the concept stage, we primarily assess the students' 'Professional Fundamental Knowledge', 'Problem Identification and Formulation', 'Written Communication', and 'Reading and Understanding Professional Literatures'.

Step2: Designing stage

In the design stage, the students must finish the design of the system plan and draw a functional block diagram of the system based on the system goals and requirements. They must also formulate a detailed project development plan, cultivate a good learning attitude and develop industrial product design skills. Students then install related software development environments and drivers to prepare for the design and implementation of the project. They design the circuit schematic diagram and PCB diagram for each functional module of the intelligent car using a combination of their professional knowledge of circuits and signals, and by researching related design information. They must use their experience with existing circuit design to determine if this can be applied to the intelligent car project. In addition, the students need to check the design rules and be sure that the design for the manufacture of the PCB is valid, and establish requirements for the hardware manufacturing process. At the later part of the designing stage, the students will generate photo plots of the designed PCBs and send to the related PCB manufacturing unit to create a printed circuit board for the intelligent car project. Therefore, in the designing stage, we will assess the students' 'Professional Knowledge', 'Learning Attitude and Habits', 'Understanding Needs and Setting Goals', 'Designing a Sustainable Implementation Process', and 'Hardware Manufacturing Process'.

Table 3. Intelligent car project development process and skill standards assessment scoring instruction

Project Developing Process	Assessment Content	Score	Scoring Standards	Total Score	Index of T-C Skill Standards(3rd-Level)													
					1.2.1	1.3.1	2.4.1	3.1.1	4.1.3	4.2.2	4.3.1	5.1.2	8.6.1	8.8.1	8.8.2	8.8.3	8.8.4	8.8.5
Conceiving Stage	Datasheet Reading	5	analyze requirements,search and read datasheets,5 points	15	4			3	3	5								
	Technical Report Writing	10	requirements analysis, principle analysis, technical report, 10 points															
Designing Stage	System Design	5	system design scheme, system block diagram, 5 points	30		5	5					5	5	5	5			
	Development Environment Building	5	(AD17, Keil5, Driver),5 points															
	SCH	10	SCH(power: 2, detection module: 3, driver module: 2, mainboard: 3),total 10 points															
	PCB Layout	10	PCB(power: 2, detection module: 3, driver module: 2, mainboard: 3),total 10 points															
Implementing Stage	Circuit Board Welding	5	good welding quality, 5 points	35							5			5	5	10	5	5
	Circuit Testing	5	no problem in circuit testing, 5 points															
	Coding	15	total 15 points (program flow: 5, code structure: 5, function realization: 5)															
	Hardware Software Integration	5	download, debug, 5 points															
	Teamwork	5	teamwork, answer questions in turn,5 points															
Operating Stage	Oral Exam	10	professional knowledge: 5, system scheme: 5	20		5		5										10
	Function Verification	10	tracking: 3, running: 2, servo controlling: 2, communication:3															

Step3: Implementing stage

In the implementation stage, the students in each project team execute the project according to their designated roles. Using the circuit design, the students will acquire the required components and welding tools, and weld the chosen electronic components to the printed circuit boards to fabricate the required circuits. After the completing the circuit board welding, the students must determine the quality of solder joint and the circuit reliability. The circuit board performance is then tested and verified using a multimeter, an oscilloscope and other instruments and equipment, to test the electronic connectivity, integrity of the chip performance and that the output signal waveform is correct. After testing the circuit board, the students must assemble the model car using the assembly instructions, and connect all the functional PCB modules in the model car using generic cabling to complete the assembly of the car. The software will be developed by research and discussion in the group to ascertain the best software using the software design flow chart for each functional module. This will include writing the code, compiling, debugging, running and downloading the program into the software programming platform. This will entail modular programming ideas, programming languages and knowledge of MCU development. The students will then complete the integration of the hardware with the software. Therefore, in the implementation stage, students' will be assessed in how they 'Form Effective Teams', and 'Design a Sustainable Implementation Process', 'Hardware Manufacturing Process', 'Test &Verification &Validation &Certification', 'Software Implementing Process', 'Hardware Software Integration' etc.

Step4: Operating stage

In the operation stage, the functions of each teams' intelligent car are verified including the tracking function, detection function, wireless communication and turning angle etc. In addition, the intelligent car project establishes an innovative function assessment item that requires each project group to design at least one additional function in the intelligent car, such as obstacle avoidance and remote control. An oral examination of the students is conducted to determine their application knowledge of the microcontroller, the principles of each circuit, the problems encountered in the development of the project and the solution process. Therefore, in the operation stage, students are assessed for their 'Professional Knowledge', 'Problem Identification and Formulation', 'Test & Verification & Validation & Certification'.

Developing detailed assessment and scoring standards is valuable to teachers, and it also conveys the teachers' expectations for the students' performance through scoring standards. Since these same standards are used throughout the class, the students are assured that the evaluation is fair and objective. But the construction of the assessment is time-consuming and challenging; therefore, it must be taken seriously, studied and researched by the teachers.

ASSESSING STUDENT PROJECT SKILLS ACHIEVEMENT

The assessment of the relative achievement of students' profession skills for this practice project is the final and the most important step in the evaluation process of learning. Evaluation results were obtained through the project development process assessment and record of each student's skills, and the analysis of collected data. These data are used to determine the learning level of each student and skill achievement of the entire course of study. In addition, these data are used for the final measure of each skill index compared to the expected learning outcome that was established set by the course plan. The teaching, learning and overall course plan can then be improved by analyzing the results of the evaluation.

The results for an individual student and the average grade for the entire class are used as examples to determine the skill achievement as an evaluation results. Table 4 shows a representative student's skill achievements, while Table 5 lists the calculation for the achievement of a representative class. A radar chart was plotted using the average achievement from Table 5. Figure 3 shows a comparison of the actual learning outcomes and the expected learning outcomes for students. The teaching effectiveness of this course can be analyzed using the results shown in Table 5 and Figure 3. As shown, the intelligent car practice project produced students with good T-C skills that allowed them to grasp the 'Reading and Understanding Professional Literatures (92%)' and '1.2.1 Professional Fundamental Knowledge (89%)'. However, the skills that were not as well developed included '2.4.1 Introduction, Digestion, Absorption and Re-innovation (66%)' and '1.3.1 Professional Knowledge (71.1%)'. We can understand the advantages and disadvantages of the teaching process by the analysis of its learning effectiveness. For the unsatisfactory aspects, a careful analysis should be conducted of the causes, so that corrective measures can be formulated to strive for improvement and overcome the drawbacks. This course of action will help us to achieve continued improvement.

Table 4. Scores for a representative student's skill standards assessment

Project Developing Process	**Assessment Content**	**Score**	**Index of T-C Skill Standards（3rd-Level）**													
			1.2.1	**1.3.1**	**2.4.1**	**3.1.1**	**4.1.3**	**4.2.2**	**4.3.1**	**5.1.2**	**8.6.1**	**8.8.1**	**8.8.2**	**8.8.3**	**8.8.4**	**8.8.5**
Conceiving Stage	Datasheet Reading	5	3			2	3	5								
	Technical Report Writing	10														
Designing Stage	System Design	5		4	3					4	4	4	4			
	Development Environment Building	5														
	SCH	10														
	PCB	10														
Implementing Stage	Circuit Board Welding	5							5			4	5	7	4	4
	Circuit Testing	5														
	Coding	15														
	Hardware Software Integration	5														
	Teamwork	5														
Operating Stage	Oral Exam	10		4		4										9
	Function Verification	10														
	Total	82	3	8	3	6	3	5	5	4	4	8	9	7	4	13
	Full Scores	100	4	10	5	8	3	5	5	5	5	10	10	10	5	15
	Achievement	82.0%	75.0%	80.0%	60.0%	75.0%	100.0%	100.0%	100.0%	80.0%	80.0%	80.0%	90.0%	70.0%	80.0%	86.7%

Table 5. Skills achievement of a representative class

Number	Name	Achievement of T-C Skill Standards （3rd-Level）														Total Achievement
		1.2.1	1.3.1	2.4.1	3.1.1	4.1.3	4.2.2	4.3.1	5.1.2	8.6.1	8.8.1	8.8.2	8.8.3	8.8.4	8.8.5	
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
12	WZ Cong	75.0%	70.0%	80.0%	75.0%	66.7%	80.0%	80.0%	80.0%	80.0%	90.0%	90.0%	80.0%	80.0%	73.3%	79.0%
13	QQ Zhao	100.0%	80.0%	60.0%	87.5%	100.0%	80.0%	80.0%	60.0%	80.0%	70.0%	80.0%	70.0%	80.0%	66.7%	76.0%
14	Shuai Li	100.0%	90.0%	80.0%	87.5%	100.0%	80.0%	80.0%	80.0%	100.0%	90.0%	90.0%	80.0%	80.0%	80.0%	86.0%
15	Zhe Cui	75.0%	80.0%	60.0%	75.0%	100.0%	100.0%	100.0%	80.0%	80.0%	80.0%	90.0%	70.0%	80.0%	86.7%	82.0%
16	Tong Zhang	75.0%	70.0%	80.0%	75.0%	66.7%	60.0%	80.0%	60.0%	80.0%	80.0%	80.0%	70.0%	80.0%	60.0%	72.0%
17	XT Ren	75.0%	80.0%	60.0%	87.5%	66.7%	80.0%	60.0%	80.0%	60.0%	70.0%	70.0%	70.0%	80.0%	66.7%	72.0%
18	XP Han	100.0%	70.0%	80.0%	100.0%	66.7%	80.0%	80.0%	80.0%	80.0%	70.0%	80.0%	80.0%	80.0%	86.7%	81.0%
19	ZX Li	75.0%	60.0%	60.0%	87.5%	66.7%	60.0%	60.0%	60.0%	60.0%	60.0%	70.0%	60.0%	60.0%	66.7%	65.0%
20	QL Guo	100.0%	80.0%	80.0%	100.0%	66.7%	80.0%	80.0%	80.0%	80.0%	70.0%	80.0%	90.0%	80.0%	93.3%	84.0%
21	Liang Xu	50.0%	60.0%	40.0%	75.0%	66.7%	60.0%	60.0%	60.0%	60.0%	60.0%	70.0%	60.0%	80.0%	60.0%	62.0%
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
Average Achievement		89.0%	71.1%	66.0%	72.8%	85.7%	92.0%	80.0%	76.4%	82.4%	75.1%	81.3%	78.3%	74.6%	81.9%	78.4%

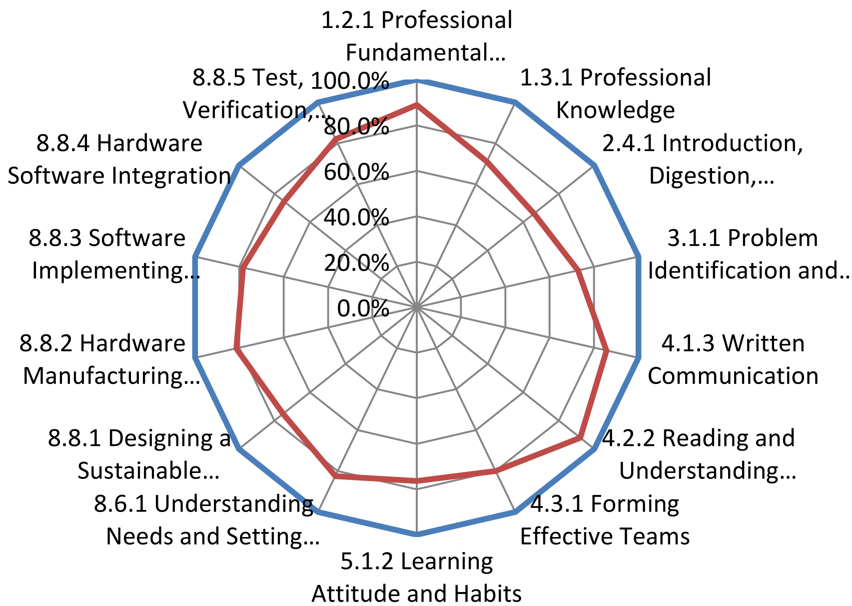

Figure 3. Analysis of radar chart for the intelligent car project

CONCLUSIONS

In this reported study, an intelligent model car system was used as a demonstration of a learning assessment system. The learning objectives (CDIO STANDARD 2) of the project were established as four dimensions that included electronic information system, personal ability, teamwork and construction of the an intelligent model car model. In addition, the intelligent car system was fabricated using the integrated CDIO learning experience which included the following stages concept, design, implementation, and operation. The work performed in each of these stages was assessed to determine the achieved skills to determine if the talent training objectives were consistent with the engineering practice process (CDIO STANDARD 7). This process included questioning the students, having them complete assignments, write technical reports, as well as assessment tables, oral exams and other diversified assessment methods. This process increased the reliability and effectiveness of the assessment data, but also allowed for a more reliable measurement of student achievement (CDIO STANDARD 11).

Compared with References [4] and [5], this evaluation method focuses on the practical process of students, and which is more extensively to outcome-oriented-ability assessment. The analysis method of skill achievement used in this study that was based on a practice project can be used to measure the specific learning outcomes of each student, and can also be used to determine the skill achievement by the overall learning outcomes of the course. The results of this analysis can serve as a basis for teachers and students to continuously improve and enhance their learning outcomes.

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BIOGRAPHICAL INFORMATION

Hua Shen is a professor and the director of electronic engineering department. His current research focuses on embedded system, artificial intelligence and on curriculum development methodology. He taught the course of intelligent electronic system and program language.

Fei Gao is an instructor of the electronic engineering department. Her current research focuses on embedded system and on curriculum development methodology. She taught the course of intelligent car practice project and digital logic circuit design.

Long Liu is an associate professor and the vice-director of electronic engineering department. His current research focuses on embedded control system, artificial intelligence and on curriculum development methodology. He taught the course of intelligent car practice project and principles & applications of microcontrollers.

Ernan Ju is the head of the electrical and information engineering major of the electronic engineering department. His current research focuses on virtual manufacturing and mechatronics. He taught the course of intelligent car practice project.

Xue Han is an instructor of the electronic engineering department. Her current research focuses on embedded system. She taught the course of intelligent car practice project and data structure.

Corresponding author

Prof. Hua Shen
Dalian Neusoft University of Information
No. 8 Software Park Road , Gan jing-zi
District, Dalian, China,116000
86-0411-84832209
shenhua@neusoft.edu.cn

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TURNING PROGRAMMING INTO A RELEVANT TOPIC FOR NON-PROGRAMMING ENGINEERS

Erik Berglund, Dennis Persson
Department of Computer and Information Science, Linköping University, Sweden

ABSTRACT

In this paper we present an introductory course on programming for about 190 mechanical engineering, design, and product-development engineering students. These students use 3D-modeling software to develop physical products. Programming is one of the tools in their toolbox, and writing algorithms can both improve the efficiency of their work and transform their work process.

At the heart of the course, in line with CDIO Standard4, is a focus on real-world applications in an introductory programming course. Understanding why and how programming is a useful tool is considered to be of equal importance to learning fundamental programming concepts.

Here we present and discuss the course and how we plan to change it in the future. We report the results of student evaluations and our own experiences. Our results, thus far, show that the applied approach has been instrumental in turning programming into a relevant topic for these non-programming engineering students. Currently, however, there is also a relatively long period of frustration and students experience an inability to use documentation and online resources. Moving forward, we plan to add a crash course with a traditional focus to the first week of the class, before starting on the applied work. It is our belief that this will make students feel more secure, and as a result allow them to be more self-sufficient in overcoming the practical challenges they face in the course.

KEYWORDS

Introduction to programming, CDIO Standard 4, Blender 3D, Python.

INTRODUCTION

Finding ways to connect the real world for to introductory courses and to allow students to use fundamental concepts to build “real” things is central to the CDIO standards. The standards highlight the applicability of knowledge, even at an introductory level. For non-programming engineering students, programming can often be seen as theoretical, abstract and complicated. This can be discouraging, and the real-world applicability of basic programming concepts can be hard for students to see.

When tasked with constructing a new introductory programming course for 190 mechanical engineering and design and product development engineering students, this was an obvious challenge. These students are not computer-science engineers and thus are not motivated by the subject matter, and few have prior knowledge of programming. A show of hands during the introductory lecture in 2017 showed that less than 10% had done programming exercises before.

Our goal was, and continues to be, to construct a course that would teach the basics of programming while still being directly relevant to the students' future career. We wanted to find ways where each student could complete a project on their own at the end of the course that, in their mind, would represent a real task, while still maintaining the basic and abstract building blocks of programming at the center of the activity. Also, for many students, using code in 3D modeling and simulation software for the construction of physical products constitutes a new perspective on the work process. Thus, one goal of the course is to introduce how code can enable creativity in an engineer's work.

CDIO Standard 4 in particular is relevant to the design of this course. For example, Standard 4 emphasizes that introductory classes should "strengthen [students'] motivation for the field of engineering by focusing on the application of relevant core engineering disciplines". (CDIO Standards 2018). Using Blender 3D (www.blender.org), which is free and open source software for 3D modeling and simulation, we address programming in the domain of constructing physical products and using code as one of the tools available to achieve such goals. Students use Blender 3D in subsequent courses, and it is well-documented by a large community of YouTubers. The scripting language for Blender 3D is Python (www.python.org), which is one of the world's most used programming languages and also a common first language at universities.

The course also address aspects of Standards 5 and 7 in ways that are natural to the course. Standard 5 states that courses should emphasize "…engineering activities central to the process of developing new products and systems." And Standard 7 states "… students might consider the analysis of a product, the design of the product, and the social responsibility of the designer of the product, all in one exercise." (CDIO Standards 2018). For these students, programming is a new tool that enables efficient workflows, but it also changes the potential work process from solving engineering challenges to using code to control the computer, and allowing the computer to solve certain engineering challenges for them. There are also more sophisticated applications which lie beyond the scope of this course, such as the use of machine learning and artificial intelligence for generative algorithms that search for optimal physical constructions. Standard 7 also addresses the issue of engineering and its impact on the world. This course has a natural connection here, where one logical application of generative design is minimizing the use of materials while maintaining constructional requirements.

In this paper we discuss our course on the fundamentals of Python programming, in which we teach our non-programming engineering students how to use Python, in conjunction with the 3D modeling system Blender 3D, for the construction of physical products. We present an evaluation of the students' perceived attitudes and discuss how to change the course in the future to improve this applied introductory course. A main component of this plan is the addition of a crash course on more traditional discipline training right at the beginning, to ensure that the students have enough basic knowledge to become more self-sufficient in using online resources and search results that are not adapted to a more applied approach to learning to program.

THE ROLE OF PROGRAMMING IN PHYSICAL PRODUCT CONSTRUCTION

The construction of physical products using 3D modeling and simulation software, like Blender 3D, includes programming as one tool in the toolbox. Much like manipulating the model using a mouse and keyboard, engineers can write code that can create, manipulate, and analyze models, and moreover can automatically repeat such a process until a sufficient solution has been reached. A significant new aspect of product design is algorithmic or generative design; see for instance Krish (2011). Currently, machine learning and artificial intelligence in relation to the construction of physical products is also very relevant.

Creating and evaluating parameterized 3D models, manipulating, deleting and minimizing materials, and running physical simulations – all of these things involve designers using code to search for physical constructions. This changes not only the efficiency of development but also has an impact on the creative process.

At the same time, a process that is a hybrid of hand-made and code-driven design may ultimately be more time-efficient than a fully-automated process. Real applications may include very few lines of code and yet may still be representative of real use-cases in industry.

RELATED WORK

Other work that relates to ours includes efforts to change standard approaches to how introductory programming courses are taught, and work on increasing integration of elements of the CDIO Standards and pedagogical elements like constructive alignment to achieve more or deeper learning outcomes, or to encourage more efficient teaching methods for better learning outcomes. A general approach to learning to program is to place a substantial amount of emphasis on practical work, "… on practice, practice and practice" as reported by Winslow (1996).

Prost (2016) reports positive motivational effects from adding degrees of freedom that allow students to make choices about parts of their tasks, but also notes that this challenges the teachers, making it harder and more time-consuming to prepare for this openness. Phae et al. (2014) and Martínex and Muñoz (2014) reported positive findings from organizing introductory programming classes into larger teams of up to 5 people, saying that it was both good for learning and more motivational. Here the assessment process was also changed in order to support students teaching each other. More social and reflective assessments were required. An alternative position was presented by Gaspar and Langevin (2012), in which traditional pair programming was replaced by a process of initial individual preparation followed by pair programming. Also, utilizing automated test systems, Gaspar and Langevin used an exchange of tests among student pairs as a means of getting students to generalize their solutions beyond "what works". Reng and Kofoed (2012) also reported on how inspirational events, field trips, and tasks related to image processing have been instrumental in changing the degree of motivation and quality of work produced by non-programming artists and creative professionals that need to have more programming skill for their future careers in the interactive media and games industry. Vo et al. (2017) identify issues associated with using applied and practical work in courses, including that (a) students and teachers may confuse a working system as equivalent with knowledge, (b) a good technical solution doesn't necessarily represent a real learning outcome and (c) there is a risk that failure in the task could be perceived as failure in learning.

Lots of practical work would seem to be a central feature of introductory classes, but it is also important to find good ways of encouraging students to become more oriented towards deep learning. We have initially worked very hard to find the balance between applied challenges and keeping the focus on programming fundamentals. In the future, we want to change activities and assessment methods to avoid shallow learning, and to address the emotional experience of being introduced to programming.

PEDAGOGICAL APPROACH AND COURSE DESIGN

Constructive alignment means finding alignment between learning goals, learning activities and assessment. As a consequence, a student-focused process is needed, in which teachers are part of the supporting environment (Biggs & Tang, 2007). Practical work has been identified as the key activity in enabling novices to become competent in programming (Winslow, 1996). Furthermore, Gagné and Deci (2005) argue that autonomy is an important motivational factor in the learning process.
The goals of our course are to:

- Understand how programming can be used in the production of physical products as one of the available tools in 3D modelling software
- Understand basic concepts in programming like variables, lists, loops, conditions and functions

Additional goals, in the current embodiment of the course, include:

- Working partly by hand and partly in code to see how code, as a tool, compares to other tools
- Using random generation and physical simulation as tools for construction to experience the potential of algorithms for solving problems or generating candidates for a creative process
- Visualizing the algorithmic process so that students can see what the code can do
- Running large numbers of experiments on models, and then validating and sorting the models to see the scope of the algorithmic potential

To achieve balance between autonomy and a tutoring-based style of education, the course is based on the students working on a series of construction challenges in a supporting environment. This includes:

- Labs, with detailed step-by-step instructions about both how to solve the challenge and how to write the code. The labs vary in complexity, but the final lab is as complex as the project. These are like interactive lectures.
- Tasks, with detailed instructions about how to solve the challenge, but not how to code the individual steps. Knowledge about coding, learned in the labs, is applied and repeated here.
- A project, where the students are given only a high-level challenge and must both break down the challenge and code it.

Students work in pairs and are primarily assessed by demonstrating their solution in person. Examination is oriented around being able to explain how the solution works, and grading is based on approving solutions that are adequate in principle. Formative feedback is also provided on how to improve for the next challenge. The project is presented at a closing seminar with a slide-show presentation. Essentially, if a student can demonstrate sufficient ability for the last lab, the tasks, or the project, then they have learned the basics of programming. To address the goal of understanding when and why to write code, we tailor the challenges to illustrate how code can help students achieve things they cannot practically do by hand.

We aim to provide alignment between real-world applications and programming fundamentals by generating, evaluating and comparing large numbers of models. This leads to the need to run loops, evaluate conditions, sort and check data variables, and to keep track of candidates over several steps in the process.

A supportive environment is provided, which consists of lectures, flipped-classroom lectures, tailored material, online support forums, screencast videos, and links to online material. Multiple weekly sessions with assistants in computer labs are also provided, which is very common in our courses at the department. This is currently the most important but also the most troublesome supporting activity. Students are allowed to work on their own time and simply demonstrate their abilities if they are able.

Project 2017: searching for legs

In 2017, the project in the course was to focus on finding leg positions for an asymmetrical tabletop that the students themselves create following a screencast video of a manual process in Blender 3D. Valid leg positions (3 or 4) are positions such that the table doesn't fall over even with weights placed at strategic positions. Figure 1 shows screenshots of such a project.

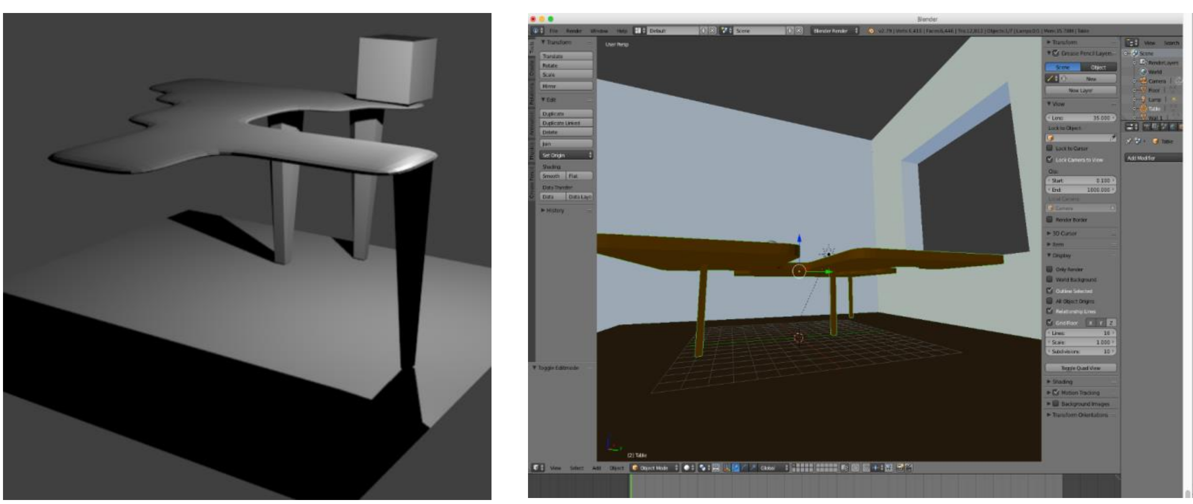

Figure 1. The legs of the tables are generated and validated by code in the search for stable leg-positions for a man-made asymmetrical table. Physical simulation and validation of hundreds of possible candidates are often needed to achieve 10 working tables.

The goal is to identify possible portions of the model for 3 or 4 legs:

- Locate and randomly select possible leg positions on the tabletop
- Add legs and simulate to see if the table is stable
- Simulate with strategic weights and test for stability
- Iterate and find 10 working leg-combinations, often generating more than 100 tables to find solutions that work
- Compare tables that are stable in terms of their leg positions and sort them for a human decision-maker (e.g., eliminate very similar solutions)

The students work partly by hand, to create the asymmetric tabletop and to find positions for weights that fit the table. They then write code to run the process of generating, evaluating and comparing tables that use random selections of legs. The process requires a minimum of about 160 lines of code, so this assignment is not overwhelming.

Using Blender 3D and Python as a platform

In our opinion, Blender 3D is a very good platform for introductory programming in general, but it is particularly good for this group. Blender 3D is a massive system, but the subset of data and functions we needed is very limited, and we find that the code written in our challenges is very much focused on the fundamentals of Python programming, rather than specific Blender concepts. Also, there is a strong conception of general algebraic and 3D concepts like vectors, locations, dimensions, and normals, as well as to physics and physical simulation with forces and torques, which our engineering students learn about in other courses. Other programming concepts such as algorithms, data variables, and flow of execution are also clearly represented.
One of the really interesting possibilities with Blender is that we can visualize an algorithm as it generates and manipulates the 3D scene to show how the algorithm works. The developer has fine-grained control over how the scene updates, and Python can easily be paused if the process runs too fast to be visible.

Blender also has a built-in Python editor, and code can be run directly inside Blender with the click of a button, making it easy to use without setting up the coding environment. One problem is that the editor doesn't autosave, so students may lose code if they are not careful.

We experienced memory-related problems, leading to Blender crashing, that were caused by the students but were too hard for them to understand. Data needs to be deleted in a particular way, and storing data has already been deleted can lead to severe problems. Because of how the Blender data model works, there can be an invisible build-up of memory usage, causing execution to become increasingly slower over time. This can be avoided in the future by changing our challenges so that deletion is not part of the process, and an initial clean-up can be copied-and-pasted into the students' programs at the start of execution.

Course Evaluation

In 2017 we evaluated the course using a questionnaire, and the students also evaluated the course in class workshops (5 classes). Our interest was in their attitudes towards programming in general and towards programming as a tool for them specifically. We are well aware of their actual abilities based on their work, and this is also presented here as an Examiner's reflection.

Student enquiry and evaluation

Out of the 190 students that took the course, 120 students participated in a questionnaire with 19 questions about their attitudes towards programming, their ability to code before and after the course, and their attitudes regarding the subject matter in relation to their future careers. The questionnaire didn't ask about sex or age, but for this student group (190 students of which 120 answered), about 30% were women, and the age range was 19-23. Questions where formulated to evaluate the student's opinions about their abilities before and after the course and their attitudes towards programming as a subject and their opinion about its relevance for their future career. Questions were of the type,

> "Did you think programming was hard before the course",
>
> "Is programming relevant in your future career?" and
>
> "Would you be able to correct simple errors on your own?"

Students were asked to answer each question with one of the following:

> (a) Yes, agree strongly (b) Yes, to some extent (c) No, not at all (d) Don't know

On average, the data showed that they had little previous experience and thought programming was hard before the course. They learned a lot and felt they would be able to write simple programs and fix simple errors, but were less confident about their ability to write error-free code at the level required by the project completely on their own. They still felt that programming was hard, but they thought it was relevant to them and wanted to learn more.

From the students' own workshops, the students expressed a general appreciation for the subject matter, and for the applied, open and adaptive nature of the course. They felt that the course was very relevant for the program, and that the level of difficulty was reasonable. They complained about not getting enough direct assistance, needing more concrete lecturing and material, and feeling lost and uncertain about requirements. They also raised the problem of not knowing enough about how to use documentation, online resources and search results. They stated that it was hard to appreciate lectures at the beginning of the course due to a lack of basic understanding of programming fundamentals.

The Examiner's reflection

During the two years in which we've run this applied introductory course, the course has successfully provided relevant learning outcomes with both of our goals in mind. In our opinion, the students learn about the same amount as other student groups that take non-applied courses. In 2017 (unlike 2016) our challenges also clearly demonstrate the ability to use algorithms to transform work processes. Students have learned basic programming for real tasks, writing small programs on their own and independently fixing normal introductory code errors.

Also in 2017, we feel that we have achieved better alignment between applied real-world tasks and maintaining focus on fundamental programming models. The generation of multiple models that are simulated physically, evaluated for validity, and ultimately compared with one another with regards to physical criteria, leads to code that is full of fundamental loops, conditions and variable management, and even sorting and development of non-trivial sorting functions. In fact, by allowing the students to manually manufacture the components we can spend more time focusing on programming fundamentals. In 2016 we worked more with managing the camera, adding and changing materials, printing images, and so forth, but this led to code with a large number of Blender-specific function calls stacked on top of one another, and emphasis on algorithmic work was sacrificed.

By adding more challenges related to finding a working candidate with minimal material, we both increase the focus on algorithms and address environmental aspects in engineering, as stressed in CDI Standard 7 (CDIO Standards 2018).

The students complain about needing more concrete and direct help, about not being able to work on their own, and about feeling frustrated and insecure. This has led to increased pressure on assistants and long waiting times in the computer labs, which in itself creates more frustration. While they receive a great deal of support, more so than many computer-science engineers, the students have an insatiable appetite for direct help, which may indicate that we have another problem. Helping them with their challenges in computer labs, as we do at our department in most of our courses, does not seem reduce this appetite. It seems that we have a trial-and-error situation in which students tend to “shake the box” until it works, as Gaspar and Langevin (2012) put it. Perhaps we achieve our learning goals because the students shake the box the same way many times. But the experience that programming is frustrating and hard is a real problem.

For 2017 we created a much larger amount of specially tailored documentation and online material on the course home page, including screencast videos. This did not really improve the situation. In fact, I suspect that the problem cannot be fixed by providing more documentation, more precise and concrete instructions, or even more screencasts (though I have more hope for screencasts). I think this needs to be managed with less direct help and more social, reflective, deep-learning activities on programming in Blender 3D, rather than focusing exclusively on solving suitable challenges.

One student team expressed that:

> Since we were often late to the computer labs we would frequently not get a seat, and this lack of help was the reason that we understood so much at the end of the course.

A few students expressed that they were able to complete the project in a day, because they had really acquired the necessary skills. This is our desired result, but for many others it took much more time and was still frustrating on a fundamental programming level. It’s clear that many students had not achieved the level of understanding that we would like them to have by the time they started the project.

Ultimately the students came out with about the same knowledge in 2017 as in 2016, at the intended level of the course. In my personal opinion (having taught programming courses since 1997) they achieved about the same level as many other students. But the students are frustrated, require a lot of direct support, and have a troublesome journey, which reduces their opinion of programming as an enabling technology. There is also cause for concern that this could negatively impact their future efforts and achievements, as Lishinsky et al. (2017) show that negative associations with performance in the past can lead to negative performance and emotions in the future.

Also, one thing that was optimal in 2017 was doing serial physical simulation, see for instance the project description in section 0. This led to the need to delete objects (to clean up before the next iteration) and results being removed and only stored as data. Nothing was visible to students if they didn't actively code for that visibility. In 2018, we should work with parallel simulation and avoid deleting objects during the script execution, which means that the students will come out at the other end with a sea of models that have all been simulated, and with the ability to see all of it over and over again, even to publish it as a video. This is an easily fixed problem that will make a big difference for the course, and for these non-programming engineering students, by giving them a better sense of the value of code.

In terms of working partly by hand and partly in code, we still find that students tend to use more code than necessary, and that they get focused on solving problems only using algorithms. Several challenges in 2017 were more easily solved by using more modelling, and the challenges also illustrated the use of components to support the programming and to create conditions. We believe that changing the structure of some of the learning activities and making them more reflective will help the students to see the whole problem and not just the programming aspects. Here, we also see potential to increase the autonomy by directing students towards creating more steps manually and then running code to address the challenges.

DISCUSSION AND FUTURE COURSE DESIGN

For the future, we want to introduce a crash-course in the first week of the course to get everyone up and running very, very quickly. Not because the students don't learn what they need to learn, but because the students feel frustrated for too long. That feeling needs to be avoided by actually learning a large volume of information quickly in the beginning, which is in line with the findings of Lishinsky et al. (2017) that negative experiences in programming have a negative impact on students' future learning.

We plan to do this in seminars with relatively small groups, with scheduled activities that require active participation, in which the purpose is to experiment, discuss and understand. Also, we are inspired by the findings of Phae et al. (2014) and Martínez and Muñoz (2014) that teams of up to 5 could provide better learning outcomes than individual and pair work, so we want to try larger student groups.

A potential outcome of a traditionally-focused crash course is being able to give the real-world challenges with less specific instructions and more open-ended requirements. Currently we have highly specific instructions with many details that students can misinterpret.

The second thing we want to do is introduce more time between asking for help and receiving help. Deep-learning-oriented help takes time to create, and in the computer lab there is too much pressure on assistants to help quickly and move on. If assistants have more time to answer, the quality should go up and students should get more value out of the help. This, we believe, is more easily done via an online forum than in personal meetings in computer labs. Personal meetings are still needed, but we are planning for flipped-classroom sessions where the students' problems are discussed rather than offering them direct assistance during programming.

To keep our applied approach, we can also develop challenges that include more hybrid development with more hand-made parts. This means that we can have real tasks and more autonomy, without affecting the amount of code required, and even find challenges where very, very small amounts of code still constitute a real application of programming for the student group.

CONCLUSION

We have applied a very real and practical approach to an introductory course in programming to a group of non-programming engineering students, as is stated as a goal in CDIO Standard 4, and which is related to many other CDIO standards such as 5, 6 and 7. Our experiences are very positive, and so is our student group, but learning programming fundamentals comes late in the course, which has led to feelings of frustration and an inability to use documentation, online resources and search results.

As a result, we want to shift the focus from application to discipline in an early segment of the course, with deep-learning activities such as experimentation and discussion in seminar groups, before turning to more applied programming exercises. Though we find that the applied approach works very well to motivate and teach programming to non-programming engineers, it should be supplemented by an initial, quick infusion of traditional teaching to avoid a prolonged sense of frustration.

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BIOGRAPHICAL INFORMATION

Erik Berglund, Ph.D. in computer science and an Associate Professor at the Department of Computer and Information Science and has taught programming in applied courses since 1997 at the university of Linköping.

Dennis Person, Ms. C. is a Teaching assistant at Department of information and computer science and instrumental in the development of the course discussed in the paper.

Corresponding author

Dr. Erik Berglund
erik.berglund@liu.se
Linköping university
Department of Computer and Information Sceince
SE-581 83 Linköping
+46 28 10 00

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COLLABORATION BETWEEN DUY TAN UNIVERSITY AND HIGH SCHOOLS: A REPORT ON THE SUPPORT PROCESS FOR HIGH SCHOOL SCIENCE AND ENGINEERING FAIR

Dong T L TRAN, Bao N LE, Duong VU and Tan TRAN

Duy Tan University, VIETNAM

ABSTRACT

Recent collaborations between Duy Tan University (DTU) and local high schools in Danang City and Quang Nam province in the Vietnam Science & Engineering Fair (ViSEF) have yielded successful outcomes through a series of awards won by students from these high schools at the fair. The collaborations, however, also revealed a number of gaps and issues in the approach of faculty members and students at both Duy Tan University and its high school partners, namely: (1) incompatible communication styles, (2) initial lack of trust in the skills and capabilities of both sides, and (3) different creativity techniques and project management schemes. Previous skills and knowledge acquired by DTU faculty members from the CDIO Initiative, however, turned out to be very helpful in bridging these gaps, especially regarding CDIO Standards No. 4, 5, 6 and 7. In particular, DTU faculty members have created a “crash” course to quickly teach high school students and teachers about the CDIO model and framework. An informal process of “design-and-trial” was also developed to help run many student projects at the same time, and to build trust between DTU and its partners through incremental progress in these projects. And yet, another major challenge was to get high school students and teachers to become involved and make effective use of the engineering labs at Duy Tan University despite their lack of previous formal training in such engineering fields. This paper, through a series of semi-structured interviews with both DTU faculty members and its partnering high schools’ students and teachers, will provide a qualitative look into the opportunities and challenges of collaboration between a university and partnering high schools in engineering projects. The recognized roles and techniques of CDIO for smooth collaboration in these projects will be examined and emphasized.

KEYWORDS

CDIO, design-and-trial, partnership development, students’ engineering projects, university-school collaboration.

INTRODUCTION

The Intel International Science and Engineering Fair (Intel ISEF), a program of Society for Science & the Public (the Society), is the world’s largest international pre-college science competition. Each year, approximately 1,800 high school students from more than 75 countries, regions, and territories are awarded the opportunity to showcase their independent research and compete for on average $4 million in prizes. Today, millions of students worldwide compete each year in local and school-sponsored science fairs; the winners of these events go on to participate in Society-affiliated regional and state fairs from which the best win the opportunity to attend Intel ISEF. Intel ISEF unites these top young scientific minds, showcasing their talents on an international stage, where doctoral level scientists review and judge their work.

Every year, Vietnam is one of the countries that always have high school students with their project attending the Intel ISEF and have won many awards. The projects were selected from the annual Vietnam Science & Engineering Fair (ViSEF) with more than 400 projects from many high schools across the country, including Danang City and Quang Nam province. With many experiences in teaching and supporting students to participate in international science and technology competitions, Duy Tan University has had positive support for high schools in these two provinces. Over the years, we've found that these things really have yielded successful outcomes through a series of awards won by students from these high schools at the fair. In the recent two years, with the support of Duy Tan University, both Da Nang and Quang Nam have achieved remarkable results. In 2016, Da Nang won 2 second and 2 third; Quang Nam province won 2 first prizes, 1 second prize, 3 encouragement prizes in nearly 300 projects of 33 schools nationwide; In 2017, Da Nang won 1 first prizes, 3 third prizes and 1 encouragement prizes.

The relationship between Duy Tan University and secondary schools is conducted in three stages:

- The DTU faculty members go to high schools to participate in the process of consulting, evaluation and approval of projects. At this stage, the high school will organize the idea contest. Here students are free to speak and present all their ideas to the judging panel. This council is composed of teachers of the university and high school teachers. The results of this internal competition will help the high school select the best and most viable project teams. Of course, the selected projects will then receive editorial suggestions from the council and especially from the teachers of the university. This gives students a more realistic view of their ideas.
  ○
- Project teams from high schools send their students to practice and implement the project in the labs of the university. Typically, each project in the field will be assigned to the corresponding lab. Each lab will have faculty members assisting students to develop their ideas into prototypes. In particular, the labs of the two faculties of the environment and electronics often receive groups of students to practice.
  ○
- Within 1 to 2 weeks before the official competition, teams will be required to report to the advisory board. The task of the advisory board is to review the entire project and make adjustments. The adjustments are mainly soft skills such as presentation skills, interview skills ...

The initial deployment process is quite convenient. High school students and teachers are excited to come to practice at the university. This is an opportunity for students to access modern equipment and devices that are not usually available in high school. However, over a period of time, this collaboration has had some problems. There are a number of gaps and issues in the approach of faculty members and students at both DTU and its high school partners. This will be discussed in more detail in the next section.

SOME ISSUES AND SOLUTIONS IN THE SUPPORT PROCESS

Normally, when we come to work at any high school, we bring 5 to 7 faculty members (figure 1). Each of them is an expert or has extensive experience in areas such as Information Technology, Mechatronics, Electronics and Embedded System, Behavioral and Social Sciences, Biochemistry. These are the main areas of the 22 scientific research areas that are defined by the ISEF for each subject [3].

Figure 1: DTU faculty members participate in the advisory board

At the first stage, our faculty members will be organized into an advisory counseling board to assist students. In this process we encountered many obstacles as follows:

- Incompatible communication styles. There is always a difference in the expertise and communication skills between the university teacher and the high school teacher because each of the learners is different in age and knowledge. The university environment is often student-centered. Students take the initiative in the research process; lecturers only convey the content and research orientation for students. Meanwhile, teaching methods in high school in Vietnam usually provide students with a foundation in natural science and social sciences subjects that are very good, but they make students passive and do not promote the creativity of students. This makes our teachers have a great challenge to be able to impart the skills of scientific research to students.
  ○
- The different creativity techniques and project management schemes. The students that we approach seem to have no idea about scientific research and propose ideas of scientific research. Often they get ideas from their own lives, either from their families, or from the place where they live. However, they are misleading in how to ask research questions. For each project, we always ask two questions: Q1: Who will be the most qualified to judge my project? What area of expertise is the most important for the judge to have? (For example, a medical background or an engineering background?); Q2: What is the emphasis of my project? What characteristic of my project is the most innovative, unique or important? (For example, is it the application in medicine or the engineering of the machine? Is it inserting the proper gene or the method of computer mapping to demonstrate the results?). These

are the questions that Intel ISEF recommends to project teams when they choose which type of category they will participate in. The result we received was that no student answered or answered the question correctly. For project management, it usually takes two to three months for the team to complete the project from concept selection to completion of the sample and reports. Obviously this is a very short amount of time to conduct a scientific study while students are also required to attend formal academic courses.

○

- Initial lack of trust in the skills and capabilities of both sides. Usually at the high school, each team participating in the competition has a teacher. Initially, when DTU faculty members recognized mistakes in the way students define research questions and suggested changing the approach for each project, we received the reverse reaction. Either do not care, or do not approve. It seems that high school teachers do not believe their projects are failing in approaching the problem and they do not believe the changes will make their projects better.

○

Although there are many obstacles, but with sincerity and objective feedback, we have helped high schools select the best projects. According to the regulations of ViSEF, in the national competition, each city will compete with six projects. So in each city, we choose the best 6 projects to put into the next stage. Each of these projects may be of one or more high schools or may be from junior high school. In the second stage of the support process, with previous skills and knowledge acquired by DTU faculty members from the CDIO Initiative, however, turned out to be very helpful in bridging these gaps, especially regarding CDIO Standards No. 4, 5, 6 and 7. At this stage, six teams of students are sent to the university with their project. To provide students with immediate access to state-of-the-art laboratory equipment, previously DTU faculty members had prepared some equipment for students to use as soon as they arrived at the laboratory (Figure 2). The equipment and components we prepare are mostly synthesized from the teaching of CDIO projects for DTU students. Depending on the category of project, each team will be assigned to the appropriate laboratory (Figure 3).

Figure 2: DTU faculty members are preparing laboratory instruments

As mentioned above, high school students often have to attend the mainstream curriculum, so they have very little time to practice in the university lab. Meanwhile, our greatest desire to bring students to the university is to help them experience a whole new way of learning. So, we created “crash” course to quickly teach high school students and teachers about the

CDIO model and framework. This is essential for students to have a sound scientific research process and to help them develop more effective projects. Standard 4 and 6 is used by DTU faculty to introduce students to technical equipment in labs aim to stimulate students' interest in, and strengthen their motivation for, the field of engineering by focusing on the application of relevant core engineering disciplines. In Figure 3, a group of junior high school students are introduced by the DTU faculty on conveyor simulation systems that are often used in factories. In integrating the introduction of these devices we explain to students why it is necessary to have such systems in the factories and why these systems are so designed. It is very important to help fill the gap in the way students make research questions.

Figure 3: Junior high school student beside a conveyor systems and high school student with a robot arm

An informal process of “design-and-trial” was also developed to help run many student projects at the same time. In Figure 4, groups of students are practiced in the lab with equipment and tools that have been prepared in advance by the DTU trainers. Standard 6 is applied flexibly to help students to develop the knowledge, skills, and attitudes that support product and system building competencies. These competencies are best developed in workspaces that are student-centered, user-friendly, accessible, and interactive.

Figure 4: High School Student practice in the CDIO workspaces

Through the above activities, we have helped students become familiar with a method of project implementation in a scientific way with a correct and effective process. Significant progress has been made through a number of improved projects and even completely changed designs. For example, the product supports text-to-speech pronunciation for the blind (Figure 5). Initially students designed an integrated product that included functional keys to control text reading (figure 5 – left side). However, this design still has some difficulties for users, the process of reading text is very slow because it's only read one syllable one time when user press the button. Through a series of activities carried out in the lab, students have new ideas to change the design in a more scientific way, more suitable for the visually impaired. The new design (Figure 5 - right) allows for faster reading of texts and can change the speed of pronunciation, while incorporating a specially designed rotary axis to display similar braille characters self but braille books for the visually impaired. So with the new design, people can listen to and read by hand, very convenient and easy to use.

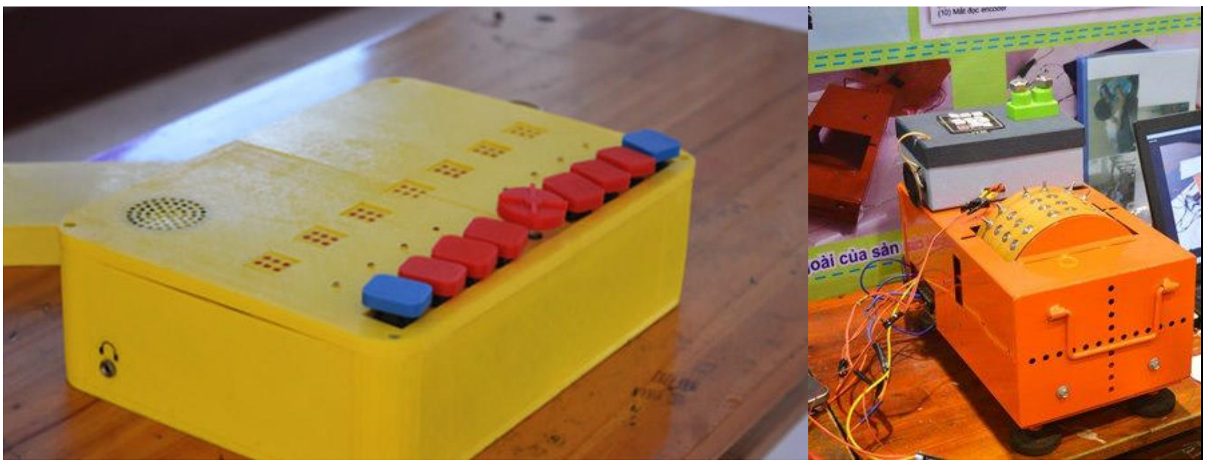

Figure 5: Text reading device for the blind

Figure 6: Equipment used to chase birds in rice fields

Another interesting project is the chasing device in rice fields. Based on the reality in the fields in the village of Vietnam, the phenomenon of birds destroying rice is very common. Due to the fact that students have tried to create a device that allows automatic chasing birds without human operators. The primary ideas of students are to use the wind to make puppets shake and birds fly. However, creativity will stop there without the support of our faculty. Thanks to this, students have found ways to improve the equipment feature and help the puppet can operate continuously thanks to the combination of wind, hydropower and combination bell to increase the ability to chase birds.

In addition to helping students improve their technical skills, at the third stage of the support process, we require students to carry out continuous reports in front of the advisory board to continue their feedback. As a result, students have improved their ability to present themselves in front of the crowd, their ability to receive and analyze questions quickly from the advisory board, their teamwork skills is also improved. Students are not afraid to report to the council. This marked improvement has led high school faculty to become more confident in DTU faculty capabilities.

Figure 7: Students are reporting to the advisory board

With the efforts of the two sides, through the progress of students in each project, DTU faculty and high school faculty have become more cohesive, the collaboration seems to have become more effective. The encouraging results from the competition are very visible, but there are also co-existing obstacles to both sides that lead to results that have not yet been met as we would like.

OPPORTUNITIES AND CHALLENGES FOR THE PARTICIPANTS

Wishing to enhance the effectiveness of the DTU and high schools through the project and provide a qualitative look into the opportunities and challenges of collaboration between a university and partnering high schools in engineering projects. We made an open interview. Through the series of semi-structured interviews with both DTU faculty members and its partnering high schools' students and teachers, key questions are as follows:

Table 1: Semi-structured interview questions

Question	Content	Interview candidate
1	Please indicate the benefits you receive when attending and practicing at DTU labs?	High school teacher
2	How do you think about the learning method that applies the CDIO model? What does it have to do with improving your projects?	Student
3	What are the difficulties you have when participating in this program?	Student
4	The level of understanding of students after approaching learning method from the CDIO model?	DTU faculty
5	Which CDIO standards are most important to help students create the ability to question the problem correctly?	DTU faculty

In the form of semi-structured interviews, we used only five key questions to collect information. During the interview, the questions will be expanded dynamically depending on the candidate's answers to clarify the issues. By collecting and compiling the information from the candidates' answers (see table of no results at 7), we draw some conclusions as follows:

Opportunities

- High school teachers and students have access to more modern laboratory equipment in labs and more resources from DTU libraries that are not available to high schools because they are not available sufficient resources.
    -
- One high school teacher declared that “the university-school collaboration has made it possible for me to watch other teachers teach and pick what is best from them and use these ideas to improve my class and with time I have learnt to carefully observe my own learning environment.
    -
- Both sides participant identified a major limitation of the nature all of the high school students candidates hardly being able to communicate well both in spoken and written English. However, the practice at DTU has created opportunities for students to improve their presentation skills in English. This is extremely important when students join the Intel ISEF in the international round.
    -
- The students also responded that they were very interested in this new method of project implementation. Especially in the process of forming the idea of the CDIO model that helped them overcome the knowledge barriers, they realized that the former things were difficult for them, now it becomes easier. They also recognize that with a problem there will always be many methods to solve, it is important to know the evaluation to choose the appropriate method. This perception opens up an opportunity for students to effectively expand their project ideas without being constrained by the amount of knowledge they are equipped with in high school.
    -

Challenges

- One expected finding was that the high school teachers identified lack of adequate resources to run the necessary collaborative activities as a major challenge of the collaboration. In the words and voice of one of the school teachers “funding of workshops and other activities are not well facilitated,” which indicates minimum administrative support.
  -
- Some other high school teachers said that the experimental equipment at DTU is modern, but the access time of teachers and students is not much (for many reasons) leading to the use of This device for their projects is not really effective. Some DTU faculty members said that high school students were not well aware of the regulations in the lab, so the practice was still flawed. Therefore, the safety requirements for students at laboratories are also a concern.
  -
- Another identified common challenge is the time to fit collaboration activities into the busy workload of the school teachers. This engagement suggests that the monitoring of the project to check on the teachers may be problematic if not well planned, and the time to run workshops if not valid may lead to problems. Lack of time on the part of the teachers could be because of understaffing and inadequate number of teachers in schools leading to heavy teaching loads in the schools. This finding agrees with the findings of [4] who indicate that among the conditions necessary for successful school-university collaboration is time commitment on the
  -
- These answers also reveal obstacles of and barriers to university-school collaboration that hinder growth of the institutions and their physical and human resource. However, the collaboration must be built on a firm foundation embedded in trust, mutuality and reciprocity [5]. The glaring benefits of the collaboration for the school teachers to grow professionally in their practices are unmistakable

CONCLUSION

Bringing students to the university's laboratories and using the CDIO model to assist them in completing their projects has helped bring about a high level of achievement in the ViSEF. This has made the leaders and teachers of high schools realize the benefits of cooperation and superiority of the CDIO model that Duy Tan University is applying. Therefore, the distance between Duy Tan University and secondary schools has been narrowed, we increasingly trust each other. This is the good way that the CDIO framework specifically help bridge the gap between the two educational institutes. For the challenges encountered as mentioned above, we have also come up with some solutions to solve them.

- Duy Tan University will sign a Memorandum of Understanding on comprehensive cooperation in the field of science and technology for provincial departments of education and training. Based on that, members between high schools and Duy Tan University will be able to easily exchange information and exchange resources (including knowledge, skills and facilities) to jointly perform tasks on science and technology, including support for science and technology competitions for students.
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- The two sides regularly organize study tours for students from the high school to the university for 1-2 days in a semester. This gives students access more often to

modern tools in laboratories. This allows them to become more proficient in using these tools.

○

- To enhance the effectiveness of supporting high school students. We have used the last year university students as good students and have extensive experience in implementing CDIO projects. They will be a significant resource to help resolve the overload of teaching and time limits for teachers.

○

Clearly, with the results achieved from the above cooperation, the role of the CDIO model and techniques applied in the implementation of CDIO models has been successfully applied by us. It helps the technical projects of secondary schools to be more complete and of higher quality.

With the problems mentioned above, we realize that the collaboration between the university and the high school in the project has really worked. Through the support of DTU, high school students have formed a scientific mindset in implementing projects. They are more responsive and identify the problem better. In addition, high school teachers have gradually changed their outlook on university faculty in general and DTU faculty members in particular. This is a favorable condition for the cooperation between the two sides to develop more widely than not only support for technical and scientific projects but also cooperation in other fields such as education set up the affiliate program. This will enable the two sides to optimize the resources of the university, reducing the cost of high schools. Beside, successful collaboration is built on coordinators and leader who communicate vision, build trust, manage conflicts, balance interests, and facilitate group interactions [6].

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BIOGRAPHICAL INFORMATION

Tran Le Thang Dong received B.S degree Electronics and Telecommunication Bachelor from Duy Tan university, Viet Nam in 2009, and M.S.degree in Computer Science from Duy Tan University, Vietnam, in 2012. He is currently a Director at Center of Electrical Engineering (CEE), Duy Tan University. His research interests include image processing, design automation of embedded systems, FPGA design. He joined the CDIO program as a lecturer of Introduction to Electrical Engineering course in 2013.

Bao N Le is the Vice Provost of Duy Tan University. He is in charge of the Technology & Science division as well as the R&D Center of DTU. His interests are in data warehousing, OLTP, graphics and animation design.

Tan TRAN is currently the Director of the Quality Assurance & Academic Examination Center, Duy Tan University. He joined the CDIO program as a lecturer of Innovative Design.

Duong Vu received his Ph.D. degree in Mechanics from Sankt Peterburg University, Russia in 1993. He is currently the Director of the Center of Electrical Engineering (CEE), Duy Tan University. He is also the Dean of the Vocational School at Duy Tan University. His interests are in welding technology, mechatronics, and professional startup education.

Corresponding author

Dong T L TRAN
Center of Electrical Engineering
Duy Tan University
K7/25 Quang Trung, Da Nang, Vietnam
(84) 511 3827 111 – (84) 935 666 394
tranthangdong@duytan.edu.vn

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INTEGRATION OF CDIO STANDARDS TO ENHANCE STUDENT'S ENTREPRENEURIAL SKILLS AND KNOWLEDGE

Duong Vu, Sy N. Dang
Duy Tan University, Vietnam

ABSTRACT

Engineering education in recent years has shifted its original focus on technical knowledge and engineering skills to more on communication and entrepreneurial skills. The emphasis on entrepreneurship is especially relevant given many success stories on EE and IT start-ups ever since the late 1990s, which indicate that an engineer nowadays require a wide variety of skills and knowledge to survive the rapid and constant changes of technology to become successful. Harsh reality has shown that engineers, who fail to move up to management positions or to start their own business by the age of 35, will be easily replaced by younger generations of engineers. Successful entrepreneurship, however, requires many things besides a good opportunity, of which creativity, flexibility, and practicability are also essential and more importantly, they can be taught. This study based on observation and interviews, followed the path of actual work and incremental progress in a student's entrepreneurship project to determine important "ingredients" in the engineering education of successful entrepreneurs. The entrepreneurship project of our focus here is the Robohand project (by Duy Tan University staff and students), which strives to provide robotic hands to people who lost their arms and/or hands at birth or due to some peace-time or war-time accidents. The study found out that not only one or two or three, but a series of CDIO standards are simultaneously needed in a systematic and integrated curriculum so as to create well-rounded graduates with strong engineering and entrepreneurial skills. Those can be identified as CDIO Standards No. 1, 2,3, 5, 7 and 8, which respectively help students identify urgent socio-economic problems, integrate different skills and know-how for feasible solutions, select the optimal solution based on strong design and implementation knowledge, and continuously improve on the solution outcomes and designs by following certain technical, social and ethical requirements. Details of this paper, as a result, will be of benefit to universities and colleges, which are looking for ways to improve on their students' entrepreneurial skills and knowledge.

KEYWORDS

CDIO Standards No.1,2,3,5,7,8, creativity, engineering ethics, entrepreneurship, entrepreneurial skills, integrated learning, robotic hand.

INTRODUCTION

In Duy Tan University we often organize activities, which enable our students to get in touch with companies, to form associations right from the time they start taking their core courses. This encourages students to select and work in areas that closely match their areas of interest. As a result of these meeting, our students can determine the target area related to their study chosen by themselves to learn better. But the thing was just halted here until we acknowledged to more explore these meetings aiming the initiation entrepreneurship from students. We realize that the project idea is the focal point of all inspiration and creativity, we therefore request that companies set fort not only simple presentation but also develop demand forecast for their products in their respective market areas. This is the most valuable source of information that will help the team to set up their rough draft of entrepreneurship plan.(Duong VU, Dong T L TRAN, Bao N LE-2017).

CDIO STANDARD NO. 2 & 3 REFOCUS FOR CONCEIVE AND DESIGN STAGES

Coming back to the CDIO Project, on stage **conceive**, all students freely discuss in teams preliminary idea of the theme they wish to follow. Initially these ideas may be unfeasible but if the proposal meets the basic guidelines and has practical applications, we encourage them follow. From the other aspect with the advanced CDIO Project, we require more personal skills, communication skills (especially oral and written English communication) and development ability, the guidance skill, systematic thinking, creative thinking, selective criticizing, problem resolving, team work (standard no. 2- CDIO Standards v 2*.0-2010*) that they have to gain conceive stage through activities:

- As a first step an instructor asks the students to provide the information that they obtained from meetings with the companies or links they formed and identified practical problems related to their subject matter mainly in the area of Mechatronics. Each student describes and outlines the outcome they envision (mind map) (Johnson, E.B.-2001) – Fig. 1. Pertaining to standard no. 2, this procedure facilitates learning outcomes, helps them to visualize what they have learnt through discussion with companies and associations.
- We encourage the students to be receptive to make changes in their initial plans based on the information they obtain in meetings with companies and associations. Having this opportunity, the students can fine tune, innovate and adjust their mind map themselves. This procedure helps students to improve their communication skills, promote creative thinking, become skilled at doing analysis and be open to critique theory in order to improve learning outcome and complete their mind map.
- We can apply this flexible model to catalyze discussions, reveal student's personal viewpoint on discerning information. Due to changing personal viewpoint, students can also reorganize their teams. We focus on problems which might be social in nature or demanded by the companies in the field of Mechatronics. The goals of the ensuing discussions may result in the requirement to deliver a complete product according to one specific operation in the assembly line, automation of some products or some types of humanitarian products which are useful to a disabled person.

The instructor then plays the role of a facilitator bridging and connecting all information, managing student's teams to conceive the idea, guide and trigger more technological, engineering aspects to help them complete their engineering conception. Based on schedule of each student's team, the instructor will monitor it so that all students during Project must plan their work load and manage their time through all stages.This is because they have many meetings, seminars, workshops, presentations with different partners in limited time and placed.

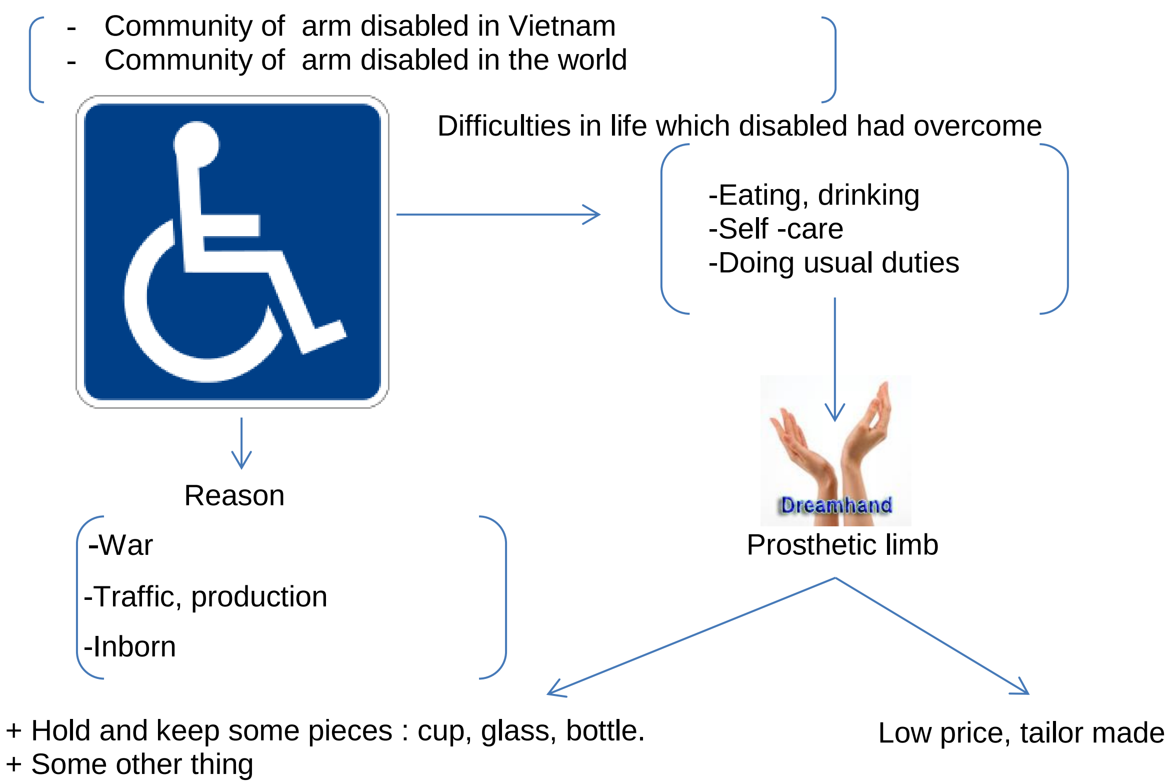

Figure 1. Mind map providing data on low price prosthetic limb for disable person.

The prosthetic limb was created by our students using the above mentioned cycle. The idea was initiated from practical demand of disabled persons not only in Vietnam but also in the world. Even though more than 45 years have passed since the Vietnam war it still has impact on our lives in many ways. The horrific memories caused a lot of mental effects to this date and produced thousands of victims who had become disabled due to exposure to toxin, bombs and other weapons of mass destruction. According to some estimates from the Department of Defense (DOD) USA, more than 15 million tons of ammunitions was used in Warfield of Vietnam and there is more than 10% that which did not explode after utilizing. This appalling figure makes people worried even in peace time.

Figure 2: Ammunition remaining from the war and its consequences

From this community many peoples lost all or most part of their arms therefore their mental and physical state decrease so strongly it affectes their quality of life. They face heavy difficulties with eating, working, self- care, and their dream is to have prosthetic limb to help them do homework. On Fig.1 the mind map synthesizes all information, collected by one team of students (standard no. 1- CDIO Standards v 2.*0-2010*).

On the stage **design**, this student's team was contacting with disable Association of Da Nang city, Quang Nam province and families to reach out to their relatives who have arm disability.They also collected additional reference , specification type of hand disabilities and started sketching design for robohand (Martin Vincent Bloedorn -2015). The youth organization of DTU is responsible for arranging contact with disable association, their families to help with the student's investigation and survey.

Fig 3. Students from DTU surveying in family of Hieu and Khoa,
Quang Nam province

Based on data collected in on-site meetings, the student's team begin the analysis, anatomy study of human hand and propose first design of prosthetic limb. At this stage besides complete teamwork requirement, all students should be proficient in specialized knowledge and advanced skill with software as Microsoft Visio, AutoCAD (Sham Tickoo- AutoCAD 2016), Autodesk Invento (Sham Tickoo- Autodesk –Inventor 2016) to develop, simulate on mechanics as well as Altium Designer to calculate the circuit board. Result of this stage is to create well thinking, technical resolutions , which meet required specification and operation of prosthetic limb –Fig 4,5,6.In the meantime,the instructor monitors and consults or answers student's questions in term of mechanical and dynamical calculations, method of data processing from sensors, to regulate limb movements. These activities are to support students to train on engineering prototype, processes and system design.

In conclusion, through communication with people with arm disability help them simultaneously learn skills in contacting, interviewing and data collection, observation, evaluation and technical proposal.

Nevertheless, the instructor also encourages students to implement AutoCAD and Autodesk to model, then create 3D printer to make the prototype. This is a very basic skill integrating in curriculum (Enelund, M., Wedel, K. M., Lundqvist, U., Malmqvist, J.-2012) to design-implement the product (standard no. 2,3- CDIO Standards v 2.*0-2010*) and could also be used as a necessary entrepreneurial skill. All students are stimulated to continuously improve on their design model together with metrology and quetionary by talking to peoples with arm diability.The studens are also encourage to find way to cut down the production cost by using alternative technology to traditional 3D in the future.

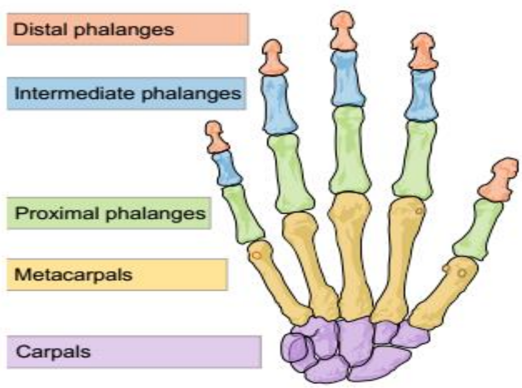

Fig. 4. Anatomy and analysis of the human hand

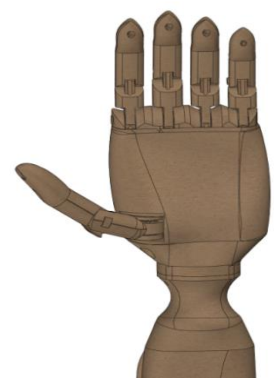

Fig. 5. Human hand design on Autodesk Inventor

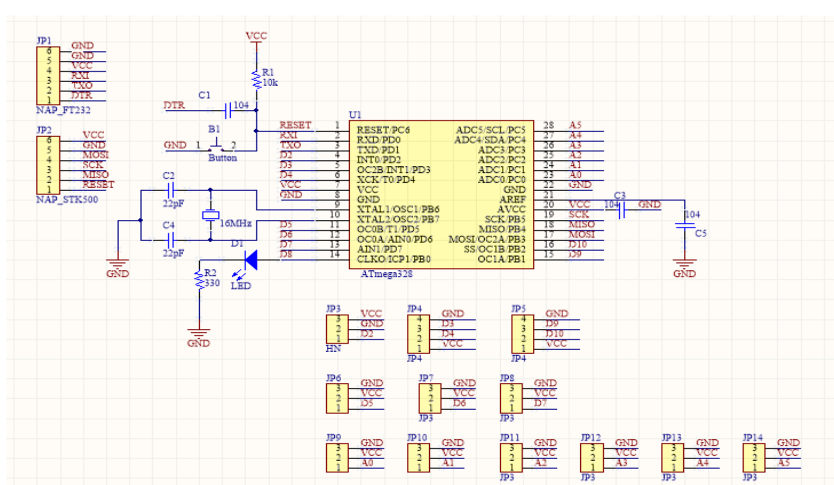

Fig. 6. Circuit Design by Altium Designer

REFOCUS OF STANDARD No. 6,7,8 (CDIO Standards v 2.0-2010) IN IMPLEMENTATION & OPERATION STAGES

Following chain of training activities, all students are being willingly and actively suggested to **implement** models, fabrication proposal, product analyze in small team collaboration, discussion, cementation each other and feed back in practice**.** This stage provide students with the experience; assignment in fabrication prosthetic limb for improving practical and professional skill; the problem solving skill (standard no.8),but the instructor only guides and suggests through connection with Center of Electrical Engineering –CEE (one of engineering division of University, having facilities for mechanical manufacturing, programming, simulation…) so that some experts at the CEE support the students to realize their ideas. The students acquire syntactic ability by themselves in one assignment including product analysis***,*** engineering and especially being responsible for social obligations of designer (Prosthetic limb***).***This is quite an unique teaching and learning activity(standard no.7) in CDIO Project which we apply in recent semester due to working technical space for students according standard no.6.All students having acquired Center of Electrical Engineering take the initiative contact with technical staff, to show their proposal and then they are allowed to use technical instruments, modern software, practical production processes right in CEE to try manufacturing of prosthetic limb – Fig- 7, 8. This methodology had some advantages as follow:

- The space in CDIO class was extended, the students are sitting not only in teaching separate rooms, but also moving to workshops, laboratories of Center of Electrical Engineering entirely close to families of disabled person. The learning in open space helped students apprehend affectively and more attractive in comparison with traditional classroom.
- Student communicated directly and worked with specialists (Thomas Erekson and Steven Shumway-2006) so it improves professional experience. The fabrication under the monitoring and surveillance of experts eliminated an mistakes, shortcoming of students due to lack of practical experience, increased the reliability of product, out coming device. Namely the Prosthetic limb could exactly operated and stably against design calculations.
- University explores maximum equipped technical facility , as research tool, to make business ,also for training. Taking advantage available machinery, materials of Center of Electrical Engineering partly helped student save research expenses.

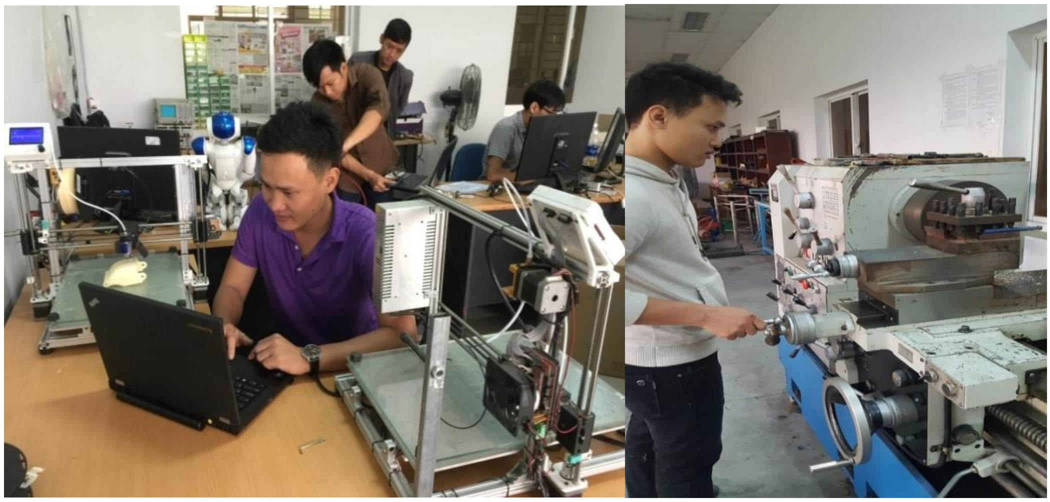

Fig- 7. Students are printing limb parts on 3D printer which made in CEE workshop

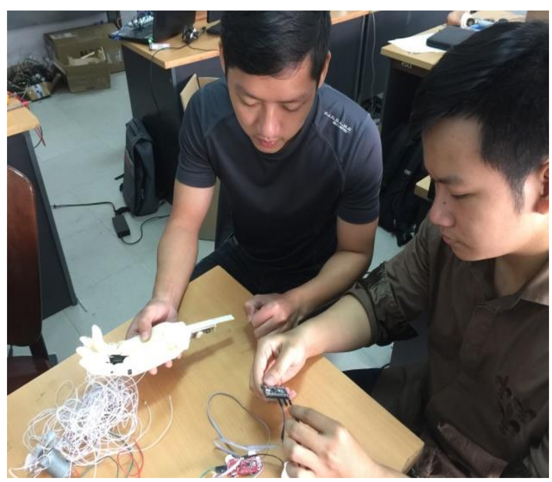

Fig- 8. Students are assembling mechanical components and electronic automation for Prosthetic limb

On stage - **operation**, the students are requested to test prosthetic limb under conditions right in company workshop. In former Projects we do not request students do this because almost results of CDIO Project was just limited on grading completeness of volume theme based on target set fort and valuated knowledge content, gaining during its execution. In advanced CDIO Project, targeting on additional arming student some more experience and entrepreneurial skill, so we got more criteria for evaluation practicability, fullness and flexibility in production conditions. Normally one Project is evaluated by complex of criterions as relevance, fulfillment of objective, efficiency, effectiveness, impact and sustainability. As an instructor we follow all criterion but we pay some more attention on entrepreneurial skills and integrated approaching in assessment.

This time, for testing prosthetic limb in workshop of company, students have been themselves establish company relation to get test permission .This helped students train confidence , independent in their carrier after graduation (standard no.8).

Fig- 9. Students taking the initiative contact with company for testing permission

Fig- 10. Testing in disabled kid family

CONCLUSION

The Project engineering prosthetic limb for disabled person is an typical example motivating the perfect integrated and simultaneous implementation of complex of some CDIO standards to strengthen, upgrade entrepreneurial skills for students in general, especially in Mechatronics. This is one new approach for circumstance analyze practice to set the social obligation for students in market study and constructive implement, combining inter branch knowledge in integrated education environment, extended space, taking advantage technology improving. It’s target for low price practical product ,paying attention on humanitarian scene. These are important knowledge and skills , arming students before joining labor market.

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BIOGRAPHICAL INFORMATION

Duong Vu, received PhD degree in Mechanics from Sankt Petersburg University, Russia in 1993.He is currently a Director at Center of Electrical Engineering (CEE), Duy Tan University. He is also a Dean of Vocational School of Duy Tan University. His interests are in welding technology, Mechatronics and entrepreneurship, professional starter education.

Sy Dang Ngoc, received B.S degree Electronics and Telecommunication Bachelor from Duy Tan university, Viet Nam in 2009, and M.S. degree in Computer Science from Duy Tan University, Vietnam, in 2012. He is currently a Vice Director at Center of Electrical Engineering (CEE), Duy Tan University. His research interests include robotics, design automation of embedded systems, Mechatronics design. He joined the CDIO program as a lecturer of Introduction to Electrical Engineering course in 2013.

Corresponding author

PhD. Duong Vu
Center of Electrical Engineering
Duy Tan University
3 Quang Trung Str, Da Nang, Vietnam
00 – (84) 913931101
duongvuaustralia@gmail.com

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PROFESSIONALISM FOR ENGINEERS: SOFT SKILLS IN ENGINEERING EDUCATION TO PREPARE FOR PROFESSIONAL LIFE

Aseel Berglund

Department of Computer and Information Science, Linköping University, Sweden

ABSTRACT

A strong set of hard and soft skills are required for an engineer to succeed in today's team-based workplaces. In order to prepare students for the profession, engineering education needs to focus on both. However, traditional engineering programs do not place enough emphasis on the development of soft skills, despite the guidelines specified in CDIO Standard 2: Learning Outcomes. Our proposition is that by focusing on soft skills such as self-motivation and personal leadership skills, students will be better prepared for professional practice and their academic performance will benefit as well. In this paper we present an innovative approach for teaching soft skills that we have implemented in the course "Professionalism for Engineers, PE" offered in two 5-year programs in computer science. A variety of tools are presented in the class and students get experience using them in mandatory assignments. Reflection is a fundamental assessment method in the course and reflective writing based on the Gibbs reflective cycle (Gibbs, 1988) is applied, as well as the Dialogue Seminar Method, to develop the students' reflective ability and to allow them to learn from their own and others' experiences. Among the lessons covered, students say the most rewarding include lessons that involve students from other disciplines, such as psychology students, and the use of the Dialogue Seminar Method with groups of students from years 1, 2, and 3. The effect this course has on academic and professional performance is hard to assess this far. Based on the experiences of the PE, a new course has been developed for two 3-year programs in computer engineering and engineering electronics. The new course is described in this paper. Students in the 5-years programs who have finished the PE will be mentors in the course.

KEYWORDS

Personal development, personal effectiveness, social competence, communication, teamwork, motivation, ethics, financial acumen, Standard 2: learning outcomes.

INTRODUCTION

Employability after higher education depends on many factors, including subject-specific knowledge, understanding and skills, emotional intelligence, work and life experience, career development, and reflection and evaluation (Dacre Pool & Sewell, 2007). One's professional success and failure are affected by possession and use of soft skills in addition to technical skills or intelligence (Goleman, 1995). Today's information technology (IT) workplaces are dynamic, distributed and complex (Joseph et al., 2010) and it is also common for engineering environments to be multidisciplinary (Nguyen, 1998). Therefore, industry expects that engineers are both technically proficient in the field and know how to behave within the organization (Nguyen, 1998). In most software engineering organizations the work is performed in teams and better results are accomplished if the teams consist of engineers with different types of personality traits with roles suited to their abilities (Capretz & Ahmed, 2010). Although engineering development is a team effort, the ability to work individually is still required and involves soft skills such as self-awareness, self-monitoring, and self-correcting (Faheem et al., 2013). According to Tong, new engineering graduates that held both technical and non-technical skills, e.g. interpersonal communication, planning, and people skills, as well as team management skills, are preferable employees (Tong, 2003). However, engineering students are not trained for professional cooperation that requires, e.g. understanding of colleagues, empathy, and self-criticism (Backlund & Sjunnesson, 2012) and it is common for engineers to learn soft skills on the job (Kumar & Hasiao, 2007). Furthermore, students do not fully understand and/or underestimate the impact of soft skills on their employability and only begin to develop an understanding after they have been hired and are working at a job (Parts et al., 2013).

Soft skills are important not only for success in professional life but also for success in personal life (Cimatti, 2016). Soft skills affect an engineering student's performance during their education (Thinyane, 2013). Soft skills refer to the personality traits and attitudes that affect a person's behavior (Roan & Whitehouse, 2007) and describe personal and social skills. Personal skills are self-oriented and refer to what a person understands and develops by herself e.g. having the capacity and desire to continue to learn, plan and achieve goals (Cimatti, 2016). Social skills are other-oriented and refer to skills a person develops in relating to other people, e.g. communication, networking, decision making, and assertiveness (Cimatti, 2016). According to Goleman (1995), soft skills are defined as emotional intelligence, which is the capacity to recognize one's own and others' feelings and is necessary for self-motivation and emotion management. Soft skills and emotional intelligence affect success or failure in one's profession and life (Cherniss et al., 2006; Goleman, 1995). For example, self-efficacy, self-confidence and self-esteem are the links between the hard skills and employability (Dacre Pool & Sewell, 2007). Soft skills lead to the development of hard skills and make it possible for an engineer to keep hard skills up to date in changing circumstances (Cimatti, 2016). It can be viewed like software on the computer, controlling and managing the hardware. Emotional intelligence is a combination of interpersonal and intra-personal competences with 12 elements that can be categorized into four domains: *The self-awareness domain* contains the element of emotional self-awareness. *The self-management domain* contains emotional self-control, adaptability, achievement orientation and positive outlook. *The social awareness domain* contains empathy and organizational awareness. Finally, *the relationship management domain* contains influence, coaching and mentoring, conflict management, teamwork and inspirational leadership (Goleman & Boyatzis, 2017). Furthermore, communication, motivation, problem solving, time management, professional ethics, and the ability to learn are examples of some of the non-technical skills that are often considered to be more important than technical skills for the engineering professional role (Kumar & Hasiao, 2007; Woratschek & Lenox, 2002). According to engineers, the five top essential skills they need in their work include: communication skills, problem-solving, teamwork, application of ethics, life-long learning, and an understanding of business (Courter et al., 2000).

In this paper, the course Professionalism for Engineers (PE) is presented together with the pedagogical basis and the lessons learned from the course so far.

IMPLEMENTATION OF CDIO STANDARD 2: LEARNING OUTCOMES

Two 5-year programs in computer science (Computer Science and Engineering, D, and Computer Science and Software Engineering, U) at Linköping University in Sweden have four aims and related goals. The aims are based on the international CDIO Syllabus for modern undergraduate engineering education programs, which presents knowledge, skills, and attitudes necessary to become successful young engineers formed by the CDIO Initiative™ (Cajander et al., 2011; Crawley & Lucas, 2011). In order to ensure that students achieve the soft skill program aims by the time they graduate, and to meet the demands of the profession of the engineering field, a new course, PE, has been designed and given in both the D and U programs (Berglund & Heintz, 2014). The CDIO Standard 2: Learning Outcomes1 and the following CDIO soft engineering skills topics are the focus of the PE course:

- 2.4.5. Awareness of One's Personal Knowledge, Skills, and Attitudes
- 2.4.6. Curiosity and Lifelong Learning
- 2.4.7. Time and Resource Management
- 2.5.1. Professional Ethics, Integrity, Responsibility and Accountability
- 2.5.2. Professional Behaviour
- 2.5.3. Proactively Planning for One's Career
- 2.5.4. Staying Current on World of Engineering
- 3.1.1. Forming Effective Teams
- 3.1.2. Team Operation
- 3.1.3. Team Growth and Evolution
- 3.1.4. Leadership
- 3.2.3. Written Communication
- 3.2.6. Oral Presentation and Inter-Personal Communications
- 4.2.2. Enterprise Strategy, Goals, and Planning
- 4.2.3. Technical Entrepreneurship
- 4.2.4. Working Successfully in Organizations

The PE course is based on four main soft skill areas: **personal effectiveness**, **personal development**, **social competence**, and **the engineering professional role**, see Figure 1. These topics were chosen based on what the industry and the engineers themselves has described as required skills, presented in more detail in the Introduction.

[1] CDIO Standards 2.0: http://www.cdio.org/implementing-cdio/standards/12-cdio-standards#standard2 (visited 2018-01-22)

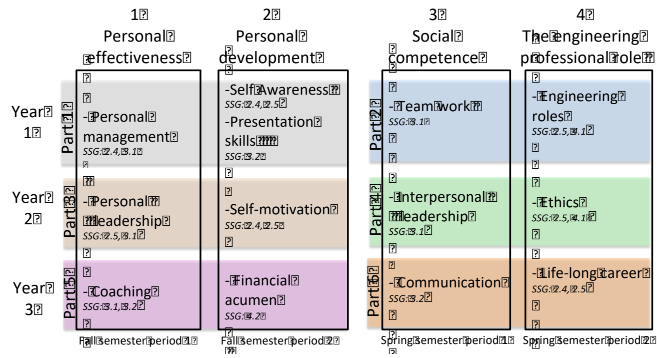

Figure 1. The content and structure of the course showing the related program soft skill goals (called SSG in the figure) and where in the course they are presented.

The PE course is designed according to the principle of constructive alignment, so students learn through relevant activities that are aligned with the intended learning outcomes (Biggs & Tang, 2011). The teachers' roles are to help the students achieve the intended outcomes (Biggs & Tang, 2011), so they are mentors in the course. Tools are presented in the course and the students gain experience using them in mandatory assignments throughout the course. The course is divided into six parts and students from years 1, 2, and 3 take it together over the three first years, with one credit earned per part. During the fall semester three parts are given, while in the spring all students take the same part, so students take parts 2, 4, and 6 in a different order depending on when they start the course. There is a progression in the topics studied in parts 1, 3, and 5, therefore the students have to study them in that order, while the topics in the spring semester do not build on each other, so they can be studied independently. For example in the personal effectiveness the students starts by learning how to manage tasks and time (part 1), then they learn to set up goals (part 3) and finally they learn how to coach themselves and other in order to be effective (part 5). In part 3 the students starts by learning setting goals in personal leadership and then they learn about self-motivation relevant for achieving the goals. In 2017 the course was taken by 389 students in total (186 students in year 1, 111 students in year 2, and 92 students in year 3). The course contains both in-class and out-of-class learning activities, as described in Figure 2. The in-class activities are: thirteen lectures, five obligatory workshops, twelve obligatory dialog seminars and two obligatory seminars. The out-of-class activities include practical work such as individual assignments and 12 individual reflection essays. The course topics are introduced through lectures and YouTube videos, TED talks, articles, and book chapters.

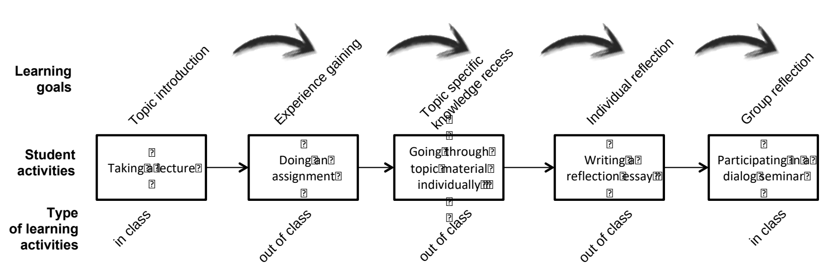

Figure 2. In-class and out-of-class learning activities

The Dialogue Seminar Method was developed in the research area "skill and technology" by the Royal Institute of Technology (KTH) in Stockholm, in cooperation with a Swedish high-tech consultancy company, Combitech (Göranzon & Hammarèn, 2006). The method has been used in training both experienced and young professional engineers with positive results in some high-tech companies (Backlund & Sjunnesson, 2012) and is used in the course to train students to increase their reflective ability and to allow them to learn from their own experience as well as that of others. To offer a more robust exchange between students with different experiences, the dialogue seminar groups are composed of 8-11 students from years 1, 2, and 3. Thus students in higher years can share their experience with younger students and hopefully serve as role models. Each student group has a teacher mentor and meets during the twelve obligatory dialogue seminars. Each seminar lasts about four hours. In order to be able to participate in the seminar, each student must perform the required assignment, write a reflection essay that is 1-2 A4 pages in length, submit it to the teacher mentor before the deadline, and bring a printed version of the text to the seminar for the other students in the group. The printed versions of the reflection essay are the entrance ticket for the seminar and participation is not allowed without them. In order to help students with the reflection process, the Gibbs reflective cycle is incorporated (Gibbs, 1988) so students think through phases of an experience or activity. The cycle guides the students through six stages of reflection as seen in Figure 3. Each stage contains topic-related questions to encourage in-depth reflection.

The Dialogue Seminar starts with a short introduction by the teacher mentor going through the agenda for the seminar. The first student then has 15 minutes and starts by handing his/her printed essay to the other students and then reading the text aloud. Next, the teacher mentor gives the group 10-12 seconds to collect their thoughts and prepare questions or comments. The group then discusses the text. When the time is up the discussion is ended and the same is done for the rest of students in the group. At the end of the seminar the teacher mentor summarizes the seminar and thanks all the students.

Examination is done continuously through related assignments, individually written reflection essays, and active participation in all mandatory in-class activities: twelve dialogue seminars, two seminars, and five workshops. Grades 3, 4, and 5 can be achieved based on predefined criteria that are known by the students in advance. When students submit their assignments and reflection essays they state the grade they are aiming for with a justification motivation based on the criteria, allowing students to practice self-assessments that can increase the student´s responsibility for their own learning (Shepard, 2000).

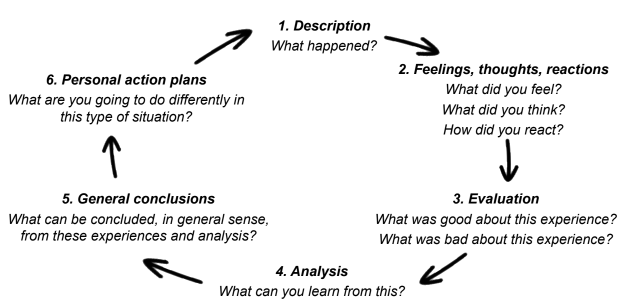

Figure 3. The review and reflection model in the PE course based on Gibbs reflective cycle.

THE PROFESSIONALISM FOR ENGINEERS COURSE CONTENT

Personal Effectiveness

Personal Management is the first topic covered. It covers planning and organizing activities in order to achieve goals, including both short- and long-term goals. An assignment consists of two parts that must be done: (1) Students obtain a calendar, plan the first period of the fall semester (to practice long-term planning) and also plan a week in detail (to practice short-term planning: weekly and daily). A workshop is scheduled where students work actively on this part of the assignment. (2) Students then keep a diary logging all their activities for the week they've planned in detail. The diary is then analyzed and a reflection essay is written based on it.

Personal Leadership topics cover understanding what one wants, being focused, and having a vision that is broken down into both short- and longer-term goals. The assignment is to identify goals to be achieved within 1-3 years and then a four-step analysis has to be performed: (1) Reflect on the current situation by answering specific questions such as *What do you like?* and *Do you have balance in your life?* (2) Define the desired situation by formulating an overall objective to achieve for an important area (e.g. education, health, social, organizational work, etc.) in a few years (the time frame is determined by the student), described by an overall SMART goal (Specific, Measurable, Accepted, Realistic, and Time-bound). (3) Create a personal development plan with sub-goals and related concrete activities. (4) Realize the plan by conducting the activities in step 3. The students also have to participate in a mandatory coaching workshop run by year 3 students studying the topic of coaching in the PE course. The year 3 students coach them in the analysis above.

Coaching highlights how to coach oneself and others and consists of six scheduled in-class activities with attendance mandatory at five, as seen in Figure 4. The assignment is to coach year 2 engineering students who are doing a Personal Leadership assignment. The engineering students in year 3 are divided into sub-groups supervised and coached by psychology students in semester seven during three consultation workshops.

Personal Development

Self-awareness is an emotional intelligence skill rooted in the ability to recognize one's own emotions (Goleman, 1995). The assignment for this topic is to apply at least one positive habit over the course of 7, 14 or 21 days to cultivate a positive mindset. According to Achor (2012) students will: (1) Write down three things they are grateful for or happy about. It has to be three new things every day. (2) Write a positive message to someone in their social support network. (3) Meditate for two minutes. (4) Exercise for 15 minutes. (5) Take two minutes to journal the most meaningful and positive experience of the past 24 hours. Mindfulness is introduced for mediation.

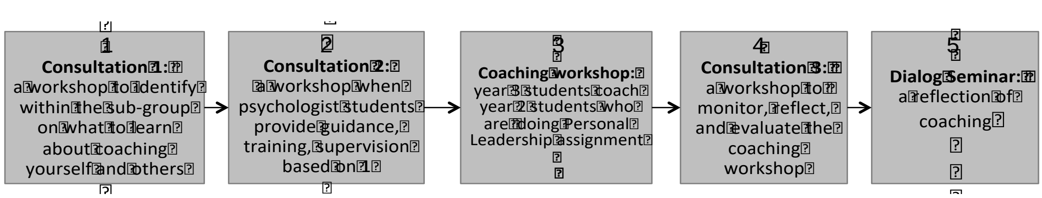

Figure 4. In-class coaching activities. Workshops 1-4 are performed without a teacher.

Self-motivation is about the ability to motivate oneself and others. The students' assignment is: (1) Do a test according to the Irrational Procrastination Scale, or IPS[2], assessing the procrastination behavior. (2) Identify what happens during procrastination by using the S-O-R-C-model (Stimulus-Organism-Response-Consequences) (Curry et al., 2003) for a week. Students identify triggers and specific situations that lead to procrastination (S), automatic thoughts, feelings, and physiological feedback (O), behavior and reaction in the situation (R), and both short- and long-term consequences (C). (3) Use a tool to increase motivation and reduce the procrastination behavior.

Presentation Skills focus on oral presentation techniques where attention is given to body language, oral performance, and visual presentation. Students participate in two mandatory seminars. In seminar 1 students give short, impromptu oral presentations to practice speaking in front of others. In seminar 2 students give a practice presentation for a project conducted in a programming course that students take in parallel with this course, and they receive feedback to enhance the presentation.

Financial Acumen is focused on developing an understanding of aspects of business and economic issues. Entrepreneurship gets special focus in the course and students can choose between two assignments: developing a business idea using the NABC business analysis method[3] or investigating and reflecting on an inspiring entrepreneur.

Social Competence

Teamwork refers to the ability to work with other people e.g. engineers, stakeholders, or customers. The students get introduced to group theories (Wheelan, 1994) and reflect on what leads to effective teamwork and personal effort in interaction with others. Students are then given an assignment where they identify two groups they have participated in, one in which the group worked well and another in which the other group worked less well. The groups they choose can be a study group during their university education or groups formed in previous work or leisure activities. The students then reflect on each group and assess what stage each group is in, according to the Susan A Wheelan IMGD model by filling in a checklist (Wheelan, 1994).

Interpersonal Leadership covers how to interact positively with others and how leadership affects productivity, looking at, e.g. leadership theories, dysfunctional teams, empathy, etc. The assignment is that students interview an engineer or a student in year 4 or 5 to gain insight into the interplay between individuals, the effect of leadership on a group, and what aspects lead to success in collaboration. The reflection essay is then written based on the interview and the student's own experience of the topic.

Communication is significant in the engineering professional role and in studying communication, students learn various non-verbal and verbal communication tools, how to ask good questions and how to listen actively. The assignment requires each student to give two people constructive feedback on behaviors that need to be changed and two people positive feedback that emphasizes positive behavior. The feedback recipient can be another student, coworker, sibling, corridor mate, football team member, etc. The students are instructed to be honest in their feedback, address real issues and use the tools taught during the communication unit. The students write a reflection essay analyzing e.g. how they usually

[2] The IPS is available at: http://fbanken.se/files/241/Irrational_Procrastination_Scale_(IPS).pdf (visited 2018-01-22)
[3] The SRI International: https://www.sri.com/ (visited 2018-01-22)

achieve their objectives in a group and how communication is linked with social competence, leadership, and success.

The Engineering Professional Role

Engineering Roles aims to give a better understanding of the engineering professional role. Students can choose between two assignments: (1) learn more about the practice by interviewing an engineer about e.g. what technologies he/she works with, what role he/she has, etc. (2) to have an understanding of the impact of the engineer's work on the environment and also to have the ability to develop solutions that minimize or prevent the environmental damages using system thinking concept.

Ethics covers four components: knowledge of codes and standards, skills that give the ability to identify ethical issues, reasoning that underlies the ability to make moral decisions, and motivation, which is the will to take action. In the course, students take part of the course content about ethics and technology e.g. *Software Engineering Code of Ethics and Professional Practice, the Swedish Engineer's Code of Conduct*, and *Linköping University's Code of Conduct for Students and Employees.* The assignment for the topic is to choose a corporation, find out the corporate ethics code or ethical policy and then identify the corporation's ethical goals and values. The student also addresses a situation where the ethical goals and values would play a role in the decisions made or actions involved.

Life-long Career focuses on having a balance in life with regard to work, health, relationships, and what brings happiness and joy in every day. It also covers building skills and knowledge continuously throughout the life of an individual. The assignment is to create a vision of life at least 10 years in the future, finding a job that the student would like to apply for in 10 years and reflecting on the competencies they need to develop and how they can develop them. Students write a curriculum vitae for the job and create a LinkedIn[4] profile if they do not have one.

Lessons learned

Possible effects on academic and professional performance are hard to assess thus far. At the end of the spring semester students complete an evaluation about their experience of the course.

Soft Skill Topics - The students are asked to choose two topics from the thirteen they think are the most rewarding. Looking at the results of year 3 students who have studied all the topics we find that the top five topics are: coaching, self-motivation, life-long career, personal leadership, and personal management. These data indicate that the interaction with students from other disciplines is interesting. Focus on planning and management is required.

[4] https://www.linkedin.com/

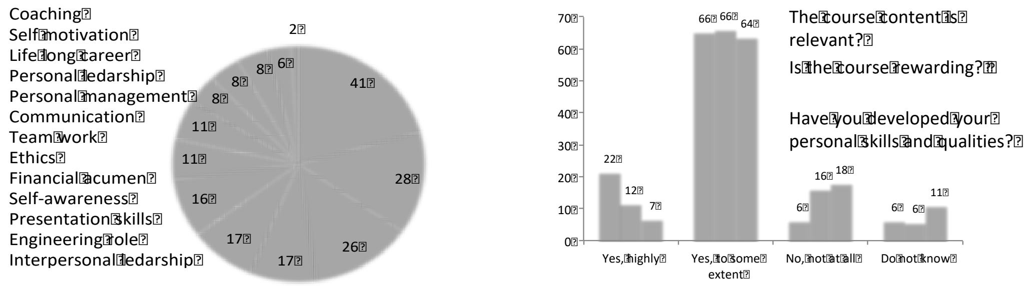

Figure 5. Left: The most rewarding soft skills according to the students. Right: The course relevance, how rewarding it was, and a student's personal development in the course.

Course Impact - Students are asked about the relevance of the course according to their own opinion, how rewarding the course is, and their development of personal skills and qualities during the course. Results show that 86% of the students find the course relevant, 78% of the students find the course rewarding and 71% of the students find that their personal skills and qualities have been developed during the course, see Figure 5. These data show that the attitudes towards the course are positive in the majority of the students.

The Course – When we ask students about what they think is the best part of the course we find that the dialogue seminars are very rewarding, since they permit students to discuss issues relevant to the engineering professional role with students from other years, they have the opportunity to share their own experiences while listening to others' and they get a chance to reflect on things that happen during the education along with others who are going through the same thing. The fact that they have to focus on soft skills is seen as positive. According to two students:

- "*The course forces us to talk and think about what we otherwise would not (for several years), partly because we are technologists and have little difficulty for soft topics*".
- "*This course leads to personal development in more areas than just programming.*"

The students appreciate the personal leadership topics and the tools for planning and managing their studies, as confirmed by the ranking of soft skill topics. In addition, the students find that it is helpful that the course is different from other courses, both in regard to content and pedagogy.

Observations - There are some students who are skeptical at the beginning of the course, while other students defend the importance of the course during the dialogue seminars. Before implementing the Gibbs reflection model (Gibbs, 1988), the majority of reflection essays contained descriptions of situations, events, or experiences and students had difficulty with analyzing and reflecting on their experiences. In addition, teachers had difficulty grading the essays. The model forced the students to analyze and trained them in reflective writing, but it can also restrict them since the steps have to be followed. Still, the teachers find it easier to grade the texts when the steps are followed.

CONCLUSION

The PE course has many benefits, even though the students may only recognize them after the course is completed. Learning soft skills by interacting with teachers as mentors, students from different years, and students from other disciplines is rewarding for the students who participate. Personal leadership and management topics are ranked among the five top topics. Based on those PE experiences, a new course has been designed for two 3-year programs in computer engineering (Di) and engineering electronics (El). The soft skill areas that are included are: **personal effectiveness** (personal management), **social competence** (teamwork and communication), and **the engineering professional role** (engineering roles). The course is studied only by year 1 students, gives 2 credits and will be offered during the second part of the spring semester at the end of the first year. The students will be divided into dialogue seminar groups with 6 students per group and each group will have a mentor who is a D or U student and has taken the PE course, so they are familiar with the soft skills areas and the dialogue seminar method. The dialogue seminars will take about two hours each. The course is graded pass/fail.

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BIOGRAPHICAL INFORMATION

Aseel Berglund, Ph. D. is Associate Professor at the Department of Computer and Information Science at Linköping University, Sweden. She is the examiner of the *professionalism for engineering* course and started the course in 2013. Her current research focuses on gamification, game development and design.

Corresponding author

Dr. Aseel Berglund
Department of Computer and Information Science
Linköping University
581 83 Linköping
Sweden
+4613281387
aseel.berglund@liu.se

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A CASE STUDY OF INTEGRATED MULTIDISCIPLINARY PROJECT-BASED LEARNING IN POLYTECHNIC EDUCATION

Vinayak Prabhu, Peter Lim, Kwek Siew Wee, Hannah Gardner
School of Engineering, Nanyang Polytechnic

ABSTRACT

Project Based Learning (PBL) is an innovative pedagogical approach to applied learning that instils critical life skills into students, making them ready to face the challenges of the 21st century. Integrating multidisciplinary and team-based instruction into the PBL makes the approach even better because students can acquire teamwork, communication, and life-long learning skills and develop an appreciation for other disciplines. This paper describes a case study of the Integrated Multidisciplinary Project (IMP) programme conducted at Nanyang Polytechnic, Singapore in which students from different faculties such as engineering, business management, chemical and life sciences, health sciences, and interactive and digital media came together to work on real-life projects over a period of six months using an underlying methodology of Design Thinking. All twelve teams successfully developed working prototypes, presented their projects in public settings, demonstrated growing levels of diverse technical and life skills through the project and reflected on their learning journey in the end to identify their strengths and areas of improvement. All the students provided positive feedback on the impact that the IMP programme had on their personal and professional development. Finally, this paper also examines the challenges faced in the implementation of IMP and discusses the potential improvements to the programme.

KEYWORDS

Integrated Multidisciplinary Project, Project Based Learning, Real-Life Projects, Design Thinking, 21st Century Skills, CDIO Standards: 3, 5, 7.

INTRODUCTION

Nanyang Polytechnic (NYP) is a public institute of higher learning in Singapore offering pre-employment training and continuing education and training diploma programmes to post-secondary school students and adult learners respectively. The polytechnic comprises seven schools in faculties of engineering, business management, life sciences, health sciences, design, digital media and information technology. It prepares students for the workforce using a contextual and applied curriculum, developed and kept relevant in collaboration with the industry. A typical diploma course is a three-year programme with core foundational modules in the first year, specialised modules in the major of study in the second and third years, concluding with industry internship and capstone project. Project based modules are interspersed within the first two years but most are individual student projects aimed at deepening the knowledge and skills in a single discipline at a time. The capstone project, a dedicated twelve-week period, is also primarily an individual student project based on an authentic problem sourced from the industry (Nanyang Polytechnic, 2018).

Increasingly, polytechnic graduates face complex challenges in their professional careers that require attributes such as resilience, creativity and multidisciplinary skills. There is also a global trend where employers place higher emphasis on 21st century skills than technical skills as necessary attributes from their workforce. (Reeve, 2016). Therefore, the curricula of higher learning must incorporate effective platforms, such as collaborative project based learning, for students to develop and demonstrate these attributes (Zhou, 2012). The Integrated Multidisciplinary Project (IMP), is a multidisciplinary project based learning (PBL) programme, that was conceived by Nanyang Polytechnic with the following five aims:

1. To engage, enable and empower students, through the medium of multidisciplinary projects, to undertake their own applied learning journeys.
2. To deepen and diversify student skills, not only in technical domains and project execution but also 21st century skills, such as collaboration, communication, critical thinking and problem solving.
3. To build students' resilience to persist and perform in challenging situations.
4. To enhance the students' presentation and public speaking skills.
5. To inspire and promote a culture of innovation whilst providing a risk-free environment.

BACKGROUND

PBL is a student-driven and teacher-facilitated approach to applied learning. Students work on a project, relevant to their domain of study, to develop solutions to real-life problems. They are guided through the process of solution development using sound methodologies under the supervision of teachers, who play the role of facilitation rather than active coaching (Scarbrough, 2004). The domain knowledge required in the project is provided to the students in advance or just in time and is applied in the project thereby enabling effective knowledge retention. Problems that present themselves during the project are solved using sustained inquiry of the underlying subject thereby allowing the students to deepen their skillsets. Students are assessed more on the process of execution and inquiry and less on the actual project outcome. Allowing students to make their own choices and honouring their individual learning styles or preferences is key to success in the PBL. Students flourish under this approach to applied learning. They gain valuable skillsets that build a strong foundation for their future in the global economy (Bell, 2010).

There are seven essential guidelines that are the gold standard for implementing PBL (Buck Institute of Education, 2015):

1. *Authenticity*: The projects are defined to solve a real-world problem. This ensures that the projects are not trivial, the learning outcomes are substantial, the requirements gathering phase is real and the project outcomes can be validated.

2. *Sustained Inquiry*: The project must have elements of problem solving that require a long period of critical thinking and analytical reasoning. This ensures that students deepen their knowledge and skills in the subjects associated with the project.
3. *Challenging Problem or Question*: The project must be challenging enough to allow the students to not only apply their own skills but also broaden and diversify their skills.
4. *Student Voice & Choice*: The students must be empowered to take charge of their learning journeys in PBL so that they take ownership of the projects and therefore commit themselves to extract maximum benefits from the project.
5. *Critique & Revision*: There must be regular opportunities for the students to obtain feedback on their projects from the supervisors and the end users so that they can learn to accept criticism, analyse the issues raised and apply their skills to resolve them.
6. *Public Product*: The students must have the opportunity to present their project to the public so that they can hone their presentation skills, learn to respond to different people with different views.
7. *Reflection*: The students must reflect on their PBL journey so that they can appreciate the importance of the process of project execution, learn from their actions and reactions to technical, personal and interpersonal issues and identify areas of improvement.

Multidisciplinary PBL is an enhanced version of the PBL in which a team of students work on a real-life project that involves the inquiry and application of multiple disciplines of study. By simulating real-life project environments, processes and expectations, but within the safe settings of the school, multidisciplinary PBL prepares students for the demands of the 21st century workplace, identified as early as the 1990s (Jahanian & Matthews, 1999). Each student not only applies and deepens his/her own domain skills in the project but also acquires the knowledge of other domains brought in by the other team members and the participating industry (Finnie et al., 2014). Students learn to work cooperatively in teams, thereby enhancing their collaboration and communication skills. They learn to appreciate the differences in disciplines, people, environments and expectations, and persist as a team towards successful completion of their projects. Students are assessed on the process and the project outcome, both as teams and as individuals (Stozhko et al., 2015). Several papers in literature have reported successful implementations of multidisciplinary student project programmes and how these programmes benefitted the students, the industry as well as the educational institutes themselves (Macklin et al., 2015, Behdinan et al., 2015 and King & Hermann, 2015).

IMP METHODOLOGY

The IMP was conceptualised to provide a multidisciplinary PBL platform to final year students from different diplomas to collaborate with each other in teams to work on real-life projects.

IMP Model

The IMP model is shown in Figure 1. The IMP is integrated within the curriculum so that students are able to devote focussed time and attention to the programme and the organisation is able to dedicate resources for its implementation. Therefore, the existing capstone project module that is offered in the final year is chosen as the vehicle to offer the IMP. The IMP is graded and contributes to the GPA of the student and is aligned to the Conceive Design Implement Operate (CDIO) standards 3, 5 and 7 which are associated with 'Integrated Curriculum', 'Design-build experiences' and 'Integrated Learning Experiences' respectively (CDIO, n.d.). The CDIO Initiative focuses on educating students to be able to participate and, eventually, lead the conception, design, implementation and operation of systems, products, processes and projects. According to Lunev et al. (2013) and Takemata (2013), project activities within CDIO include problem clarification, idea generation, selection and substantiation and prototype development, evaluation and refinement, which are essential underpinnings of the IMP concept.

In line with the PBL guidelines, the projects in the IMP are authentic, aim to solve a challenging problem and have elements that require sustained inquiry from the students. Therefore, referencing from Singapore's Smart Nation Initiative (Smart Nation and Digital Government Office, 2017), four real-world themes, namely, 'Smart Healthcare', 'Smart Mobility', 'Smart Homes' and 'Sustainable Living' are chosen for the programme.

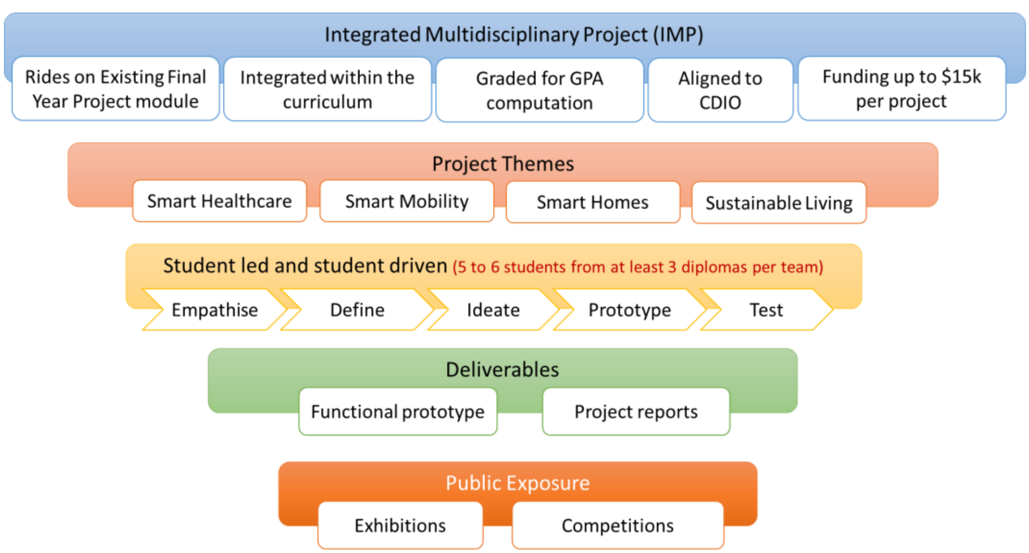

Figure 1: The IMP Model

In order to align with the PBL guideline on 'Student Voice & Choice', the IMP is designed to be 'Student Led and Student Driven'. Therefore, students form their own teams of five to six members, as long as there are representations from at least three different diplomas per team to ensure the multidisciplinary nature. Students also propose their own projects chosen from one of the four themes above. To ensure that the students understand the importance of being empathetic to the end users' needs and that they have higher chances of succeeding in their projects, all the teams are taught the 'Design Thinking' principles (Melles, Howard, & Thompson-Whiteside, 2012), which they can use to underpin their project execution.

All teams are required to deliver 'working' prototypes of their projects in 'Minimum Viable Configuration', which is at a level of completeness where the main objectives of the project are met and demonstrated. Each team is also required to submit a project report, documenting the project in enough detail for referencing by future cohorts. The teams is assessed based on the functionality of the prototypes and quality of their reports.

Finally, there are public exhibitions and competitions for the teams to pitch their projects to the public, obtain end user feedback and compete for awards. This fulfils the requirement of PBL guideline of having a 'Public Product'.

IMP Implementation

The IMP was implemented as a pilot study in 2017 by the School of Engineering (SEG) to evaluate its concept, processes and outcomes. The target was to recruit 5% of all final year students from all eleven diplomas in SEG and a maximum of six students from each of the other six schools (business management, life sciences, health sciences, design, digital media and information technology). A team of 19 supervisors and 50 domain experts were chosen from the teaching staff of SEG for supervising and guiding the IMP students.

Staff Preparation

The IMP is a deviation from the conventional project based supervision. While the intent is to promote student led, student owned projects, it is essential that the supervisors understand their roles in the execution of the IMP while ensuring that each student from different domains has a role to contribute significantly. Therefore, the supervisors were trained in facilitation techniques and best practices in student team management for multidisciplinary projects. With the diverse skills required in each project and the varied composition of students in each team, additional staff with expertise from various technology specialist centres of the school were appointed as domain experts to support the supervisors in domain specific matters. Supervisors and domain experts work closely throughout the IMP programme.

Student Selection

Students were selected for the IMP programme on a voluntary basis without any criteria on past academic performances. Using roadshows, students were informed about the programme, its requirements and its benefits while also clearly explaining the other alternatives the students had in their final year such as individual capstone projects, overseas internships and local internships before they applied for the IMP. This way, the students were able to decide judiciously based their educational and career goals.

The IMP was implemented in 3 phases:

1. *Planning Phase*
   In this phase, the IMP students formed project teams, learned design-thinking principles and identified real-world problems within their chosen themes to pick their projects. The teams used the 3-month phase to research about their projects, scope them, internalise the design thinking methodology, and identify and purchase the components needed for their projects with guidance from their supervisors and domain experts.
2. *Execution Phase*
   The IMP teams had twelve weeks to execute their projects and produce a working prototype. In this period, the students worked full time as a team with each member assigned roles according to their individual disciplines. By cross-pollinating ideas and sharing of knowledge, students were exposed to disciplines that they normally would not have experienced if they had chosen to do individual capstone projects.
   The students were in complete control of their projects right from planning, scheduling and sourcing to execution and validation. Supervisors played the role of facilitators, guiding the teams in using the design thinking methodology, pointing them to sources of knowledge for self-help and course correcting only if required. The domain experts provided targeted assistance in specific technologies that the supervisor did not have expertise in on an on-demand basis. Any conflicts arising within teams were resolved either through negotiations among the students or interventions from the supervisors.

   Once the prototypes were developed, the students conducted functional tests to verify the working of the prototypes and introduced their prototypes to the end users for trials in order to validate their projects. Some teams with business students produced business plans to take the product to market whereas teams with students from digital media produced marketing campaigns through websites, blogs and advertisement videos.

3. *Exhibition Phase*
4.
   In this phase, students worked outside their curriculum hours to participate in both internal and external competitions and elevator pitch sessions at public places such as libraries and displayed their projects in public exhibitions. This phase introduced the students to public speaking, gave them opportunities to enhance their presentations, taught them how to use elevator pitches to convince stakeholders about the promise of their projects and provided the teams with valuable feedback from members of the public comprising people from different age groups, cultures and backgrounds that enriched their learning.

Student Assessment

The IMP students were assessed both as teams and as individuals. The assessment components, for teams, were the project outcome (prototype, report and presentations) and teamwork (team dynamics, cross learning among members). The assessment components, for individuals, were professional attributes, personal soft skills and contribution of technical or domain competencies in the project.

Two assessments were conducted, one in the mid- term and one at the end in seminar styled events in which each team presented their project to an audience comprising the panel of assessors, supervisors, domain experts and other IMP teams. This way, teams could learn from each other and have the opportunity to provide peer feedback. During the assessments, the panel graded only the presentation and project outcome components whereas the supervisor assessed the teams continually through the twelve weeks on the soft skills and technical or domain competencies components. The supervisor's assessment contributed 75% of the total grade whereas the assessor panel's assessment contributed 25% (Figure 2).

	First Assessment			Second Assessment					Overall Score
	Attribute (Individual)	Technical (Individual)	Presentation (Group)	Attribute (Individual)	Technical (Individual)	Documentation (Individual)	Teamwork Performance (Group)	Presentation (Group)	
	10% of Overall	10% of Overall	10% of Overall	10% of Overall	20% of Overall	10% of Overall	15% of Overall	15% of Overall	100%
Marks	/10	/10	/10	/10	/20	/10	/15	/15	
Staff Signature		Supervisor	Panel				Supervisor	Panel	Supervisor

Supervisor: 75% Panel: 25%

Figure 2: IMP Student Assessment Form

FEEDBACK AND REFLECTIONS ABOUT THE IMP

This section presents the feedback obtained from the students, supervisors and the IMP programme committee.

Students' views on their learning experiences

All the teams provided their feedback on the IMP via testimonials. Individual students also provided their feedback via email to the supervisors and the committee. Students recognised teamwork, collaboration, peer learning, conflict management, and project planning and management as their major learning outcomes from the IMP. Excerpts from the testimonials are as follows:

"Throughout the entire IMP, we learnt that teamwork is very important and time management is very crucial. Rather than giving up on challenges, facing them together made us a better team."

"This has been a very enriching and interactive experience for all of us. We were able to use knowledge from our different courses to complete the project. We learnt new skills that we do not specialize in our individual courses."

"During the course of the project, we have had plenty of conflicts. Nevertheless, our desire to see our unique project succeed and delve into something beyond our individual capabilities helped us forge strong relationships with one another."

"What we benefited most is that we worked together as a team, overcoming challenges that none of us expected in the beginning. We learnt different skills from each other. The

experience of dealing with matters such as project planning, purchasing, execution and problem solving were pretty challenging but equally satisfying."

The students also provided feedback on improving the IMP programme ranging from a more structured approach for consultation with domain experts to incorporating peer assessments into the formal assessment system.

Feedback from Supervisors

According to the supervisors, IMP provided a rich and dynamic learning environment for the students. They observed that the motivation among the students was intrinsic and they had to do very little to motivate them through the project. They noted that since the students had voluntarily opted for the IMP, they were committed to the programme and often stretched beyond their capacities to ensure that their projects succeeded. From the supervisors' perspective, collaborating with each other, managing interpersonal and professional relationships, doing formal presentations, managing projects, accepting and delegating responsibilities, and using creativity to solve problems were major learning points for the students. The second major learning outcome was cross learning and application of skills that naturally resulted in broadening the competencies of the students.

As for improvements, the supervisors suggested that the projects could be defined and scoped by the school instead of the students themselves because often the project scopes creeped and put the projects in danger of not completing. The supervisors had to intervene in some instances, sometimes against the team's wishes, to ensure that the teams completed their projects in time. Though the teams were initially disappointed, in the end they appreciated the intervention. The supervisors also agreed with the students' suggestion that the consultation process with the domain experts could be more structured to avoid delays.

Reflections from the Programme Committee

The IMP was introduced by the polytechnic to reinforce its efforts to develop all-rounded graduates equipped with 21st century skills. By deepening discipline-specific skills, gaining skills from other disciplines and applying close articulation between theory and practice, the students honed their technical proficiencies. The use of design thinking methodology that stressed the importance of empathising with peoples' needs made the students aware of the socio-economic aspects of projects rather than just the technical ones. Because of the challenging and authentic nature of the projects, students had to solve problems using their combined ingenuity and resourcefulness. Finally, the students were exposed to a wide range of authentic professional situations such as forming teams, grappling with leadership, responsibilities and conflict management issues, communicating through meetings, writings and presentations, and setting and managing their own goals. The committee, having engaged with all stakeholders, also noted a few areas of improvement:

1. Improving the consultation process with domain experts to ensure effective coordination among staff and students without affecting the projects.
2. Providing active guidance in assignment of individual roles and responsibilities to students in a team rather than leaving it entirely to them.

3. Increasing differentiation of grades within the team, introducing peer assessments and increasing the frequency of student feedback.
4. Including more students from the design and information technology disciplines to have more diversity of skills and knowledge in the programme.

The committee also observed areas of concern during the pilot study which were similar to those identified by Berglund et al. (2007) in their multidisciplinary project based learning programme:

1. *Project Scope Creep*: As students work on their projects and get excited about the solutioning possibilities, they tend to keep adding features and functions to their prototypes thereby risking successful completion of the minimum viable product in time.
2. *Visible cooperation problems in groups*: Observed in cases where there have been differing opinions on solutions, differing personalities, disagreements on distribution of workload between team members and members not being able to meet their set targets.
3. *Non-visible cooperation problems*: This happens when the team does not acknowledge problems that exist within the team and cover up for them to not let the team look bad.
4. *Supervisory cooperation problems*: Contrasting styles of supervisors and domain experts that the same team of students interact with can create a mismatch of expectations among students.
5. *Supervisor-centred (proactive) vs. Student-centred (reactive) supervision*: This is a difficult calibration because the supervision approach must be carefully tuned to the characteristics of the team as well as personal traits of individual team members.
6. *Students stick to what they have in common*: observed in some teams as the members get to know each other well and find their "common denominators" after which they become reluctant to look for new ways of working. They take the safe route that all team members can relate to even though better solutions could be found.
7. *Student Assessment*: Students may not get regular formal feedback on their performance, given that there are only two assessments (mid-term and final) and that they find it difficult to document their concerns during the project.

CONCLUSION

The pilot study of the IMP was successfully conducted at Nanyang Polytechnic. The students involved acknowledged the benefits and learning outcomes of the programme. Supervisors observed the positive transformation of the students with respect to collaboration, communication and presentation skills, professional skills, and an increased intrinsic motivation for learning. Overall, the general experience is that students were much more committed, involved and driven than is normally the case in individual capstone projects.

Putting together a high performance team of teaching staff and educating them in PBL philosophy to provide effective and targeted supervision to the students is key to implementing programmes such as the IMP. Another key requirement is to provide empowerment to students to form their own teams, propose their own projects and take charge of project execution. It is important that the students are clear that the learning outcome is more about the process of executing and managing their projects rather than the actual prototype or solution. The pilot study also revealed areas of improvements, both from the perspective of the students and the supervisors. The programme is resource intensive, needing a team of 69 academic staff to work with the students for a period of one year from planning to execution to exhibition phases. The IMP role is in addition to the staff's regular teaching and non-teaching roles, requiring active prioritisation at the staff and department levels.

The benefits of multidisciplinary PBL far outweigh the demands of running such a programme. The results reported in this paper have given the polytechnic the confidence to establish the IMP as a mainstream programme in the curriculum that is pervasive across all schools of the polytechnic.

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BIOGRAPHICAL INFORMATION

Vinayak Prabhu, Ph.D. is a Senior Lecturer and Chair of the Integrated Multidisciplinary Project (IMP) programme at the School of Engineering at Nanyang Polytechnic, Singapore. He teaches precision engineering and digital manufacturing courses at the school and undertakes research and industry projects in the areas of manufacturing informatics and cyber security for manufacturing.

Peter Lim, is a Senior Lecturer and Co-Chair of the Integrated Multidisciplinary Project (IMP) programme at the School of Engineering at Nanyang Polytechnic, Singapore. He teaches courses in embedded systems and advanced electronics at the school and undertakes research and industry projects in the areas of AI-enabled biometrics and signal processing.

Kwek Siew Wee, is a Senior Manager at the School of Engineering at Nanyang Polytechnic, Singapore. She manages the school's academic systems and undertakes research projects in the areas of teaching and learning development, new pedagogical approaches and infusion of Information Technology in education.

Hannah Gardner, Ph.D. is a Senior Lecturer at the School of Engineering at Nanyang Polytechnic, Singapore. She is involved in teaching courses in material science and nanotechnology at the school and undertakes research and industry projects in the field of functional nanomaterials.

Corresponding author

Dr. Vinayak Prabhu
School of Engineering
Nanyang Polytechnic
180 Ang Mo Kio Ave 8,
Singapore 569830
+65 6550 0630
vinayak_prabhu@nyp.edu.sg

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ACTIVE LEARNING IN REDESIGNING MATHEMATICS COURSES FOR ENGINEERING STUDENTS

Annoesjka Cabo

Delft University of Technology, Faculty of Electrical Engineering, Mathematics and Computer Science (EEMCS), Delft Institute of Applied Mathematics (DIAM)
and
4TU Centre for Engineering Education
The Netherlands

Renate Klaassen
4TU Centre for Engineering Education – Delft University of Technology

ABSTRACT

"Prepare, Participate, Practice": active learning in designing basic maths courses for engineering students at TU Delft works! The PRoject Innovation Mathematics Education (PRIME) at Delft University of Technology (TU Delft) is all about redesigning mathematics courses for engineers. This paper describes the process of developing, implementing, evaluating and implementing again of three basic courses at TU Delft using a blended learning approach developed by a growing team of teachers from the mathematics department. Our findings suggest that the approach taken enhances students' learning performance in maths education. The main results show that students have a more active learning experience compared to the traditional setup of these courses, leading to more engagement, more interaction and better results. An important role is played by meaningful examples taken from the engineering faculty where the students are studying, showing students from that faculty what role the mathematics play in their field of interest. This is also used to develop their skills in mathematical modelling.

KEYWORDS

Engineering education, blended learning, mathematics, team-based development, active learning, CDIO- Standards: 1, 2, 8, 9, 10, 11, 12.

INTRODUCTION

I In this paper we consider interfaculty education: mathematics for non-mathematics students at TU Delft. Students need to have a sound mathematical background to pursue their studies and in their future careers. Pinxten (2017) shows that students need 6 to 8 hours of mathematics training in secondary education each week and a sufficient to very good grade at the final exam to have a chance of success in studying Engineering. Continuation of diligent study time in mathematics is a necessity for any engineering student to obtain their bachelor degree and achieve academic success.

Mathematics at TU Delft is taught within the engineering faculties before or parallel to the disciplinary courses in the engineering programmes. It allows the students, or so it is hypothesized, that students use the mathematical theory and apply it in their disciplinary engineering assignments. Despite the high expectations, the transfer of theory to practical application in the disciplinary field is limited, as shown by student evaluations, performance on exam questions and lecturer reports. From studies in childhood mathematics learning it is known the more concrete object and materials are used to learn mathematics the more difficult the transfer becomes of the mathematics to other disciplinary or isomorphic assignments. Abstract mathematics allows for better transfer and better ability to understand relational structures, allowing for math skills transfer to alternative math topics. (Kaminsky & Sloutsky, 2012). Concrete objects increases the salience of superficial aspect and divert the attention from the relational structures to be learned. The more complex the problems become the more susceptible to diverted attention the learner is.

Finally, student engagement and intrinsic motivation are stimulated by establishing more autonomous learning, a feeling of competency (self-efficacy) and relatedness to other students who may struggle with the same materials (Deci & Ryan (2002) Bandura, (1997), Artino (2012)). The present situations allow for little to no autonomy as the programme is fixed and a schedule to be met. Once the students are behind there is little time or possibility to catch up, bearing on the feelings of competencies. Frequent testing overburdens the students and possibly makes them loose their intrinsic motivation and engagement with the mathematics material.

To solve the issues mentioned above, a new teaching approach was developed in “PRIME” . In this paper the following questions are researched upon: Does the new teaching method activate/engage students (more), does it improve transfer, does it improve passing rates? First we start by describing the project. Next the development of the new approach and the didactical concept chosen are reflected upon. Then the implementation of the concept is reported, followed by the consequences and improvements implemented after the first operation of the courses. Data analysis of the results over the past two years are presented and finally some suggestions for future research are discussed.

THE PROJECT: PRIME

In 2014, PRIME (PRoject Innovation Mathematics Education) was initiated in order to conceive a different approach to the math courses for engineering students.

The organization of PRIME

The initial project team consisted of a group of six dedicated lecturers from Delft Institute of Applied Mathematics (DIAM), an e-learning developer, an educational advisor and a project leader. The project was supported by the Executive Board of the university. A large steering group was assigned to the project to keep informed about the progress: it consisted of the Vice-President of Education (Executive Board), the director of Student Affairs, the dean of the faculty of Applied Physics, the dean of the faculty of Electrical Engineering, Mathematics and Computer Science (EEMCS), the director of education of the faculty of Aerospace

Engineering, the director of education of the faculty of EEMCS, the chair of the Mathematics department, a student from the Mathematics student association. After two years of running the project, the team has expanded into a team of a senior project leader, an assistant project leader, 12 instructors, an e-learning developer, an educational advisor and four student assistants. The steering group has remained the same, except for the student member, who has been replaced by two students: one from Civil Engineering and one from Aerospace Engineering. The steering committee gathers once every three to four months with the project management team.

The goals of PRIME

Three goals were formulated:

1. *Academic success*: to improve study results
2. *Transfer*: to improve the connection between mathematics and engineering
3. *Engagement*: to increase students active participation in class and motivation for the topic

In the following subsections each of the measures taken to address these goals is described briefly.

Academic success

Once the student is motivated for mathematics, the next important challenge is to activate him: active learning enhances retention and improves understanding of subsequent subjects in the student's learning path (Veenstra-van Dijk, 2000). Moreover, it is well known that mathematics needs practice, in order to acquire the skill of interacting in a mathematical way with their disciplinary field of study, needed to learn new concepts.(Kirschner et al., 2006). Academic success is described as the measures teachers realise to sustain students' time on task. Engagement described below is the flip of the coin, the extent in which students are engaged and motivated to realise the time on task.

Transfer

Showing the use of mathematics in the field of interest of the student is believed to enhance motivation for learning (Chickering et al., 1987). With the help of lecturers and students from the receiving faculties, contextual examples from the specific fields are worked out, to illustrate the use of mathematics in the field of interest. Finding examples that are interesting, not too hard to explain for the mathematicians, not too hard to understand for the students turned out to be a challenge. A new smaller project carried out by Cabo & Makaveev (2018) has resulted in a new method to investigate the use of mathematics in specific engineering courses. The lessons learned from this project will be implemented in PRIME shortly. They involve also incorporating projects in a later stage of the courses to apply their knowledge in practice, an important feature of engineering education (Edström, 2008; Kamp, 2016).

Engagement

Engagement can be defined as the extent to which students actively participate in learning activities (online presences, watching videos and doing assignments) and face to face contact meetings (coming to class, being prepared, making use of the materials to digest the learning materials). It equally includes the stimulation of student motivation by relating abstract materials to their disciplinary field of study The extent to which students are engaging in higher education is supposed to strengthen the learning outcomes. (Trowler, 2010, HEA report)

The courses innovated in PRIME

To start with three basic maths courses were considered for innovation: Calculus 1 and 2, Linear Algebra (all first year courses) and Probability & Statistics (first or second year course). Since the context examples are tailored to each individual program, the courses are not exact copies of each other. However the content is mostly exchangeable, only the pace of each course may differ. Bachelor programs with courses in PRIME are Aerospace Engineering, Computer Science, Electrical Engineering, Civil Engineering and Mechanical Engineering. In the near future courses like Differential Equations and Calculus 3 in certain programs will also be innovated. A typical course consists of nine weeks of two or three two-hour lectures, resulting in 18 to 27 contact hours.

BLENDED LEARNING CYCLE: “PREPARE, PARTICIPATE, PRACTISE”

A number of educational principles have been included to achieve the innovation and goals of the project. Active participation in teaching sessions (Freeman et al, 2014), conceptual understanding in the face to face contact (Rittle-Johnson et al,, 2015), adequate performance feedback (Hattie 2007, Boud & Falchnikov, 2006) and a carefully balanced format of contextual examples (Cabo & Makaveev, forthcoming) using contextual problems, with a sufficient level of generalisation, to motivate the importance of maths in other fields of study and equally support transfer. In other words: the students should **prepare** themselves before coming to class, should **participate** actively by joining in-class-activities and after the face-to-face session students should **practise** to process the new knowledge. A blended approach was felt to best meet the requirements (Bonk et al., 2006; Szeto, 2014 in this context, due to the workload of teachers, increasing student numbers, the stimulation of autonomous learning, competency building and time on task. A video has been recorded, available at the TU Delft website (2017), which stimulates students to study differently.

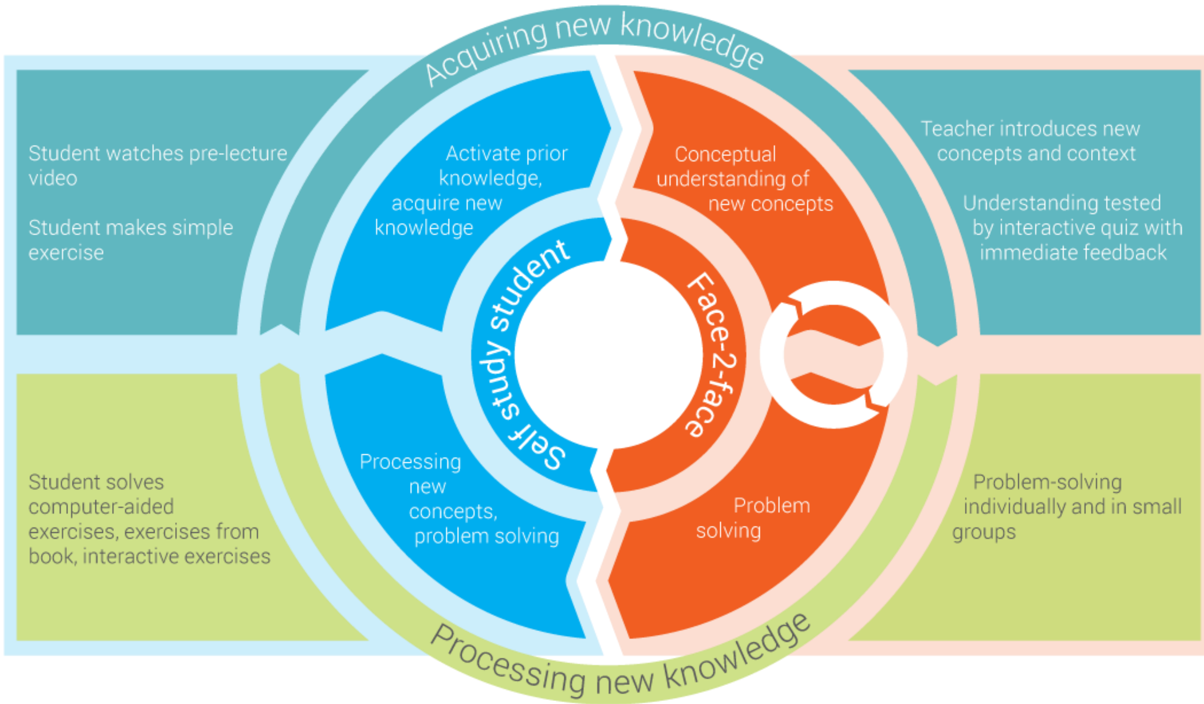

Figure 1: Blended learning cycle used in PRIME

Practise

At home (or wherever the students want), a set of computer aided exercises can be done: an online platform offers two or three types of exercises: basic, intermediate (with an optional help function to guide the student through the exercises) and an assignment, to be handed in online. At the moment a platform offered by an editor is being used, however the project management is currently looking for an (open source) alternative.

BLENDED LEARNING: MATERIAL DEVELOPED (hybrid flipped classroom)

This model of blended learning is established as a sort of hybrid flipped classroom, as shown in the sequence prepare, participate and practice, the flipped model of autonomous learning and reflection and discussion in class to further explore the learning materials is not enough. The practice step consolidation of the learned materials is essential to bring the math skills to the next level of learning.

For each course new material has been developed by the project team. During frequent meetings (once every one or two weeks), first a lesson plan was designed, with all the learning outcomes listed. Then consensus had to be reached on which learning outcome could go into the pre-lecture video, and how the others would be covered in the slides. Exercises had to be chosen, contextual examples had to be collected from the faculties and implemented into the course. An overview of the course, linking the separate subjects was constructed, and included in the collaborative learning environment, showing students how the subjects connect.

Evaluation and evolution of all the learning material is constantly being done: lecturers send their comments to a special mailbox created for this. If possible changes are implemented immediately by the student assistants. More drastic improvements are collected and stored. During meetings where new courses are being prepared for their pilots, every remark on the content, video, course structure, exercises and quizzes is taken into account, discussed, reviewed and altered if necessary.

Using the Collaborative learning environment

All the material for the course is presented to the students in a well-organized page on Brightspace, the collaborative learning environment in use at TU Delft since September 2017. The lectures are structured by week and represent the blended learning cycle.

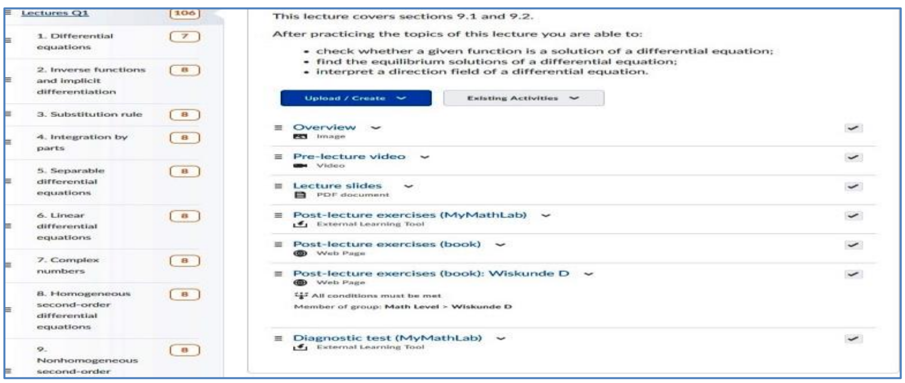

Figure 2. Example of a lesson on Brightspace

Overview

A graph representing an overview of the subjects presented in the course, shows students the connection between different subjects covered.

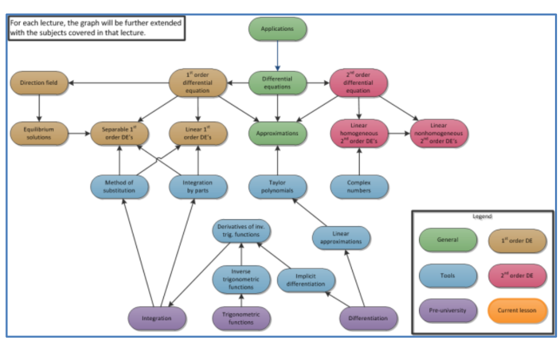

Figure 3. Overview of a course Calculus 1 (Civil Engineering)

Sub-parts of the Course design

The course consists of online exercises to practice the conceptual understanding of the subject together with the book exercises. The exercises provide feedback and allow repetition as much as needed by the students. 110 videos have been recorded covering an introductory subjects, half of them are used as a type of homologation in which students secondary education knowledge is upskilled (TU Delft, 2018). A slide pack is the framework/benchmark for all the lecturers and students involved. It includes definitions, theorems, contextual examples, interactive quiz questions, workflow of a lecture, accomplished learning goals after having done all the lectures activities and homework. Finally, there are interactive quiz questions including questions on conceptual understanding. Depending on the results of the quiz, the lecturer can decide to further elaborate on the subject and stimulates active participation of students in class. It is reported by lecturers and students that the quizzes stimulate active participation of students in class.

Mathematical modelling

One of the learning goals of the newly designed courses in Calculus was to teach the students the mathematical modelling cycle: this is the most important application of their mathematical knowledge in practice.

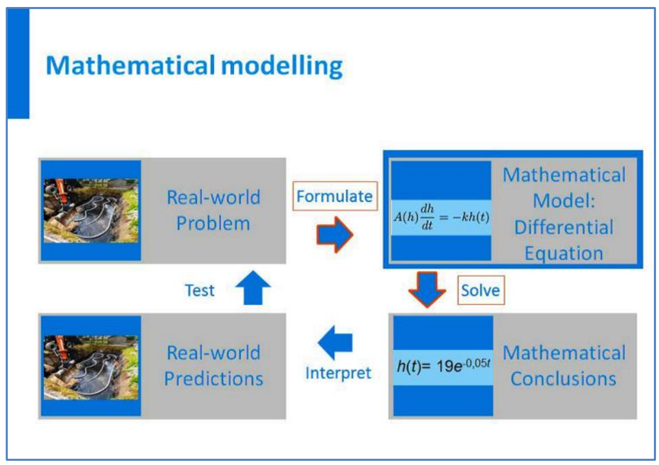

Figure 4. Mathematical model cycle

EVALUATION

The evaluation was focused on whether the new teaching method activated/engaged students (more), is transfer improved and are the passing rates improving? The data are as much as possible triangulated and emerge from data at the programme level, the lecturers and the student evaluation. At this point we were not yet able to formulate any research hypothesis.

Program directors and academic success

The program directors of the Bachelor curricula involved are pleased with the innovation: the activity of the students has increased, and – after an initial dip in the results- the study success rate has increased (Table 1) They appreciate the fact that mathematical modelling is now part of the learning outcomes, and they hear from lecturers of their own faculty that they feel more comfortable about the expected level of mathematical background of the students of their own classes.

Table 1. Passing rates

	2013/14	2014/15	2015/16	2016/17
LinearAlg AE	61%	72%	52%	75%
Prob&Stat AE	54%	19%	56%	67%
Prob&Stat EE	67%	79%	54%	70%
Calculus 1 CE	73%	68%	64%	68%

before PRIME
during PRIME

Lecturers role in the hybrid flipped model

The impact on lecturers involved in blended learning has been investigated in different ways. After the first pilot a survey was distributed among the nine lecturers who taught the course. (Vos, 2016). In subsequent courses, for each course three meetings were held to discuss the content and impact of the course: one before the course started, one in the middle of the course (week 4 or 5 of the quarter) and one at the end, after the course had finished, but before the exam was taken. The instructors commented on the use of the pre-lecture videos and how to deal with the fact that students don't watch them: 50 % of the instructors tend to repeat the material of the videos, 50 % does not, or in a concealed way. The teachers are positive about the interactive quizzes although some of them (40%) thinks it takes too much of their instruction time. Using the slide pack is for 40 % of the teachers a burden: they are used to teach the course in their own way. The other 60% however think it is helpful to reduce preparation time. All teachers have seen that the students are more active during the classes, and the attendance is higher than it was before the blended teaching. Working in a team to develop and discuss course content was appreciated by 70% of the lecturers. Observing each other's classes was viewed as a relevant and stimulating experience, helping to improve the quality of teaching. The support from the project lead was considered sufficient (70%), could have been more (30%). The cultural change needed in the teaching staff turns out to be a tough process. It takes more time to get the teachers along than it takes to convince the students. Hence the activation of students and the stimulation of time on task, may not have reached its optimal balance yet.

Students Engagement

Apart from the official quality cycle (Evasys) - a survey that students fill out after having done the exam (average response rate 30%) - the project management implemented the so-called ContinueStartStop Survey. In this questionnaire the students are asked to write down what they would like the lecturer to continue doing start doing, stop doing or. The survey is given to the students during class, the response rate is quite high (70 - 90%). The general remarks collected from this survey are grouped and the ones that appear the most are commented on by the responsible lecturer together with the project management. These comments are posted on Brightspace. The comments that relate to individual teachers are sent to the teachers, and they discuss them in class.

In the second quarter of the academic year 2017-2018 a lunch meeting with students from Civil Engineering, with part of the project team and the responsible lecturer was organized to discuss the outcomes of the survey. The use of contextual examples was highly appreciated there. The students confirmed that they liked the way of teaching and the videos, but also gave some useful feedback on individual teachers and explanation of the online exercises.

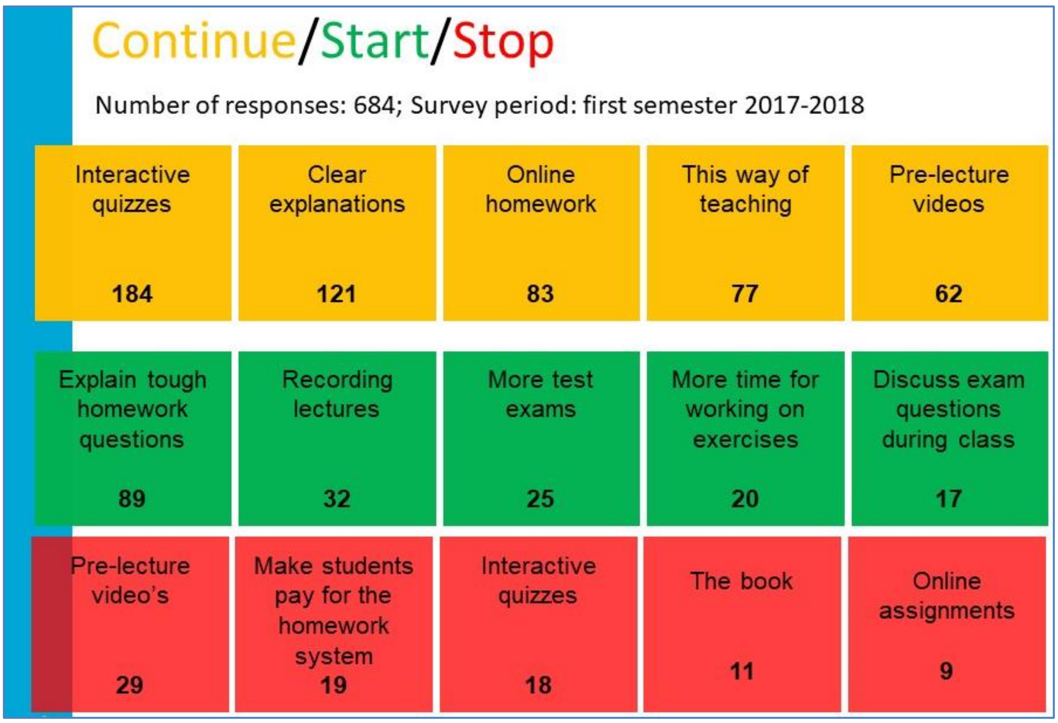

Figure 5. Outcome of the ContinueStartStop Survey in the 1st semester of 2017-2018 with 684 respondents

Transfer

Most important reviews were on the contextual examples: some of them were too difficult to understand for the students, some of them were too difficult to explain for the teachers, some were not realistic enough. Also some videos had to be recorded anew because they had too much content. Furthermore, a lot of the interactive questions were adapted because either they did not connect well enough to the videos, or they did not test concepts well enough or they took too much time to answer.

CONCLUSIONS

After three runs of the courses Calculus 1 for Civil Engineering and Probability and Statistics for Electrical Engineering, they seem to have reached a steady state. The rest of the courses, that have run two times, or only one time, need adjustments.

Working in large teams of teachers improves the quality of the courses and the consensus on how to teach the course, this is noticed by the students. Blended learning is welcomed by students, blended teaching is a challenge for some of the teachers. Finding suitable and meaningful examples to illustrate the use of mathematics is an equally tough challenge. Help from students from the relevant programs might turn out to be crucial to improve this. In one instance (Cabo, 2018) this turned out to be the solution. On the other hand the use of this kind of examples in the courses is really appreciated by the students.

FUTURE DEVELOPMENTS AND RESEARCH

In the near future, the courses are being improved using student evaluations and teacher experiences. It is interesting to find out if three runs with this intensity of adjustment and evaluation is the standard to get to a steady state situation of a course. Additionally, many research questions have emerged as a result from designing and re-designing these courses.

A lot of data is being collected from the students. Well-defined research questions should guide the relevance of the learning analytics data gathered until now and from the next academic year onward. In particular we will investigate how online individual learning paths enhance student's learning, and how active learning (time on task, engagement, motivation) effects the understanding of the mathematics taught and how the mathematic and disciplinary based assignments can be validated for conceptual understanding of the discipline.

In the academic year 2017-2018 a pilot has been done at Civil Engineering by grouping students having a similar, somewhat better, mathematical background from secondary school: Did these students perform better in the mathematics course in higher education than their less prepared counterparts? Did they appreciate the extra information and deepening of the learning experience they were offered? Is it worthwhile expanding this experiment to other faculties?

Teachers that are late adapters or have problems getting used to this PRIME approach will be supported with extra training activities. This will contribute to lifelong learning and faculty development on teaching mathematics in the PRIME model.

The lessons learned from the project investigating how to better implement the connection between mathematics and aerospace engineering, will be incorporated in PRIME and further expanded. What the most efficient way is to embed discipline based examples in mathematics or computational learning is to be explored.

The ambition is to involve the multiple stakeholders in the data collection and analysis to generate more evidence based support for the things that have intuitively been done until now and extend this to a larger community within TU Delft and beyond.

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BIOGRAPHICAL INFORMATION

Annoesjka J. Cabo, Dr. is working as a statistician and as a lecturer of Mathematics. Since August 2016 she is the director of studies of interfaculty education at the faculty of EEMCS at the Delft University of Technology. She is the leader of PRIME: Project Innovation Mathematics Education, a university wide initiative to innovate mathematics education for engineering students. As such she is involved in developing learning material, researching data from the project and coordinating a growing group of people involved in the process.

Renate Klaassen, Dr. is an educational consultant, working at the TU Delft Teaching and Learning Services. She has been heavily involved in educational advising on the innovation of the BSc in Aerospace Engineering, and various other curriculum reforms at TU Delft. Currently, she is TU Delft Programme Co-ordinator and Researcher of the 4TU.Centre for Engineering Education. Consultancy activities include assessment (policy, quality and professionalization), internationalisation of university education and design education. Areas of research interest pertain to content, language integrated learning in higher education, Conceptual Understanding in Engineering Education and Interdisciplinary learning.

Corresponding author

Dr. Annoesjka J. Cabo
Delft University of Technology
Van Mourik Broekmanweg 6
2628 XE Delft
+31-6404 301 36
a.j.cabo@tudelft.nl

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CDIO IMPLEMENTATION IN THE ICT ENGINEERING CURRICULUM – SEMESTER PROJECTS

Tauno Tepsa, Maisa Mielikäinen, Juhani Angelva

Information and Communication Technology, Lapland University of Applied Sciences

ABSTRACT

CDIO has been in the center of the new curriculum development for the ICT department of Lapland University of Applied Sciences since the year 2013. The first step was to adopt the principle that CDIO is the context of ICT engineering education and then ICT department determined the outcomes for learning of the skills associated outlined in the CDIO Syllabus. ICT program was also benchmarked against more experienced CDIO implementers to learn from the best practices.

Since then continuous improvement has been done to enhance the ICT department competence in CDIO skills. In the latest self-evaluation three main areas for improvement were identified to satisfy CDIO standards 5 (Design-Implement Experiences), 9 (Enhancement of Faculty Competence) and 11 (Learning Assessment). This document describes how the development work has been done.

While starting from the existing curriculum it was decided that the new curriculum based on project-based learning (PBL) would be piloted with selected courses. The real-life projects were from local companies and the University's cooperation R&D&I (Research, Development and Innovation) projects.

The new Curriculum in the pilot was decided to be based on 30 ECTS credits semester projects due to results of piloting other options as well. Named teacher teams who will also implement the future projects designed Eight (8) semesters. Each team was comprised of professors from various fields. The teacher team planned the integration of the selected courses for each semester – semester-based projects. Students learned to use modern project management techniques like Agile, Scrum, Kanban, Lean – skills what ICT Engineers need after finishing their studies.

The first real-life R&D&I learning projects piloted in the curriculum development support also the Lapland UAS strategy, e.g. eSled (the electric snowmobile), iLodge (intelligent Lodge for tourists) and Digital Trekking Services on the Arctic Circle. These projects are described more detailed in this document.

KEYWORDS

Curriculum, integration, semester project, case study, continuous improvement. CDIO Standards: 5., 9., 11.

INTRODUCTION

The focus of this paper is to present the results of the CDIO self-evaluation and some actions to improve them. Three semester projects will be presented as case studies. All courses were integrated during this curriculum development process. The publication is a perspective and a summary of teachers' actions and results to achieve higher CDIO level.

Self-evaluation is one part of the quality assessment of School of Industry and Natural Resources, Degree Program of ICT in Lapland University of Applied Sciences. Regular evaluations are used for developing operations and reaching the goals set by OKM (Ministry of Education and Culture) for the universities of applied sciences. These goals include e.g. maximizing the number of graduates and minimizing the number drop-outs, accomplishing 55 ECTS per year, and the overall student satisfaction (coming to the financial model). The assessment is presented at the education planning event. The teachers and R&D&I employees of the Lapland University of Applied Sciences participate the event.

SELF-EVALUATION

The first self-evaluation, applying to all CDIO principles, was made at the education planning event in October 2013. Principles 5, 9, and 11 were chosen as special areas of development based on the self-evaluation. The special areas of development were re-evaluated in the intermediate assessment of 2015, but no significant change was observed. The self-evaluation was again done for all areas of development at the end of 2017, including the three special areas.

The results of the self-evaluation are presented in table 1. The mid-term assessment of 2015 was done only for the three special areas of development, so these results are not presented in the figure.

Table 1. The assessment levels in 2013 and 2017. (The scale is 0-5 according to the CDIO Standards 2.0).

	Assessment level in 2013	Assessment level in 2017	Difference
Principle 1 **The context**	2	3	+1
Principle 2 **Learning outcomes**	2	3	+1
Principle 3 **Integrated Curriculum**	3	4	+1
Principle 4 **Introduction to Engineering**	3	4	+1
Principle 5 **Design-Implement Experiences**	3	5	+2
Principle 6 **Engineering Workspaces**	4	4	0
Principle 7 **Integrated Learning Experiences**	2	2	0
Principle 8 **Active Learning**	1	3	+2
Principle 9 **Enhancement of Faculty Competence**	0	1	+1
Principle 10 **Enhancement of Faculty Teaching Competence**	1	1	0
Principle 11 **Learning Assessment**	1	1	0
Principle 12 **Program Evaluation**	1	1	0

In 2013, the new curriculum was carried out. The new curriculum was based on project-based learning (PBL). For this reason, the following special areas of development were chosen for first development targets:

- Principle 5: Design-implement-test Project
- Principle 9: Enhancement of Faculty Competence
- Principle 11: Assessment of Learning

To enhance the level of principle 5, the degree program implemented several projects under the CDIO Framework. The principle 9 has been sided eg. by running supervisor-based discussions, and about the principle 11, the training of the improving assessment has been organized by the university.

Several projects, based on the CDIO principles, were designed and implemented to the higher level in the Principle 5. The first pilot project was carried out in spring 2014. During 2015-2016 several study modules were integrated into the projects and several seasonal projects were carried out. In 2017, all spring study modules were integrated to seasonal projects and the teachers operated as a teaching team. Examples of seasonal projects are presented later on in this document.

Special pedagogical training was provided for assessing learning and the special areas of development in teaching by the University of Applied Sciences. Project-based learning became the standard in teaching. The development of the curriculum was supported by local industry representatives and students representatives.

Based on the results, the teachers' proficiency in CDIO (principle 9) was slightly improved. In addition to the teachers' professional skills, system building skills and process and product skills, the interpersonal skills were improved. The teachers learned how to work in teams opposed to working alone without consulting other teachers. Carrying out seasonal projects (30 ECTS) should be treated as a project itself, as they require planning, management, and coordination on the teacher team's side. Teamwork among teachers is gaining more and more traction, although there are some exceptions. Supervisor-based discussions and support are very important during this process. The development of teachers' CDIO skills should still be more systematic.

Integrating study modules to projects has resulted in increased versatility in teachers' work, although it has become more demanding than before. In addition, the number of graduates and students that have accomplished 55 ECTS per year has increased after the CDIO and project-based learning was introduced.

Planning long-term teaching development is seen as necessary, as planning is still targeted towards individuals' needs, not the education itself. Monitoring OKM's targets are in active use in education, but it does not support development. Education should be assessed in the context of the development plan.

In order to achieve higher assessment levels, teachers of the degree program suggested as an improvement to receive feedback from external assessment and reviews on seasonal projects. The external assessment could be implemented as cross-reviews between other degree programmes in the school of technology. The subject is under development.

NEW CURRICULUM - SEMESTER PROJECTS

The new ICT Curriculum is based on 30 ECTS credits semester projects due to results of piloting other options as well. There are lot of experiences of project-based learning, for example, Mejtoft et. Al (2015). Learning projects are based on an agreement with either local industry or University's R&D&I (Research, Development and Innovation) projects. Eight (8) semesters were designed by named teams of teachers who will also implement the future projects. Each team was comprised of professors from various fields (Angelva et al., 2017).

Each semester is planned around a project as shown in Figure 1. The learning project is supported by the other courses of the semester. The courses are integrated into the projects to meet learning outcomes and build upon the know-how intended for the semester along with the project.

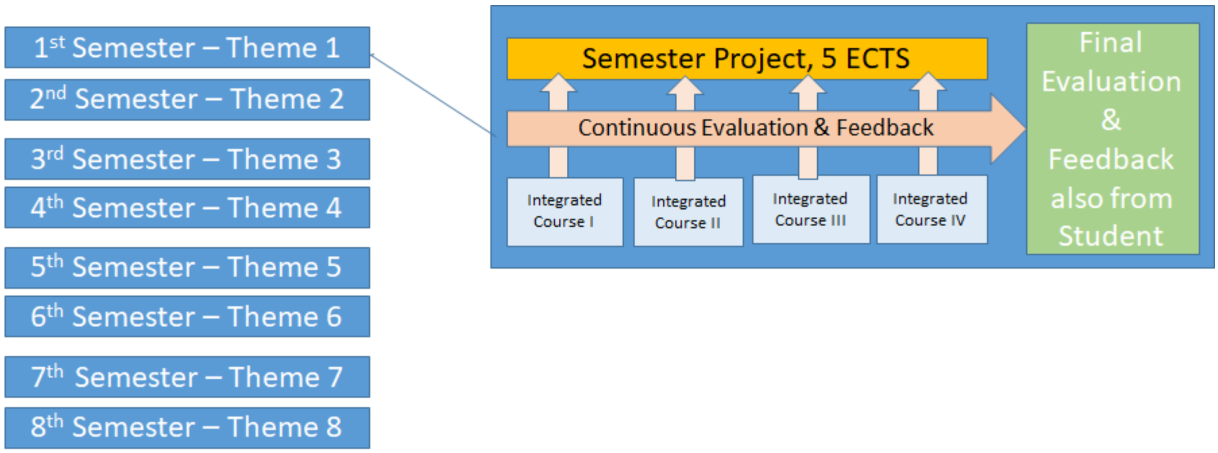

Figure 1. Fundamentals of the Semester Structure in Curriculum (Angelva et al. (2017)).

Learning Project Management

Learning projects are managed using appropriate tools. During the first integrated learning courses, project management is done and learned according to PMI's (Project Management Institute) PMBOK Guide (Project Management Body of Knowledge). While students skills have developed in project management, agile methods like Scrum is taken to use. Figure 2. shows how Scrum is implemented in the learning project.

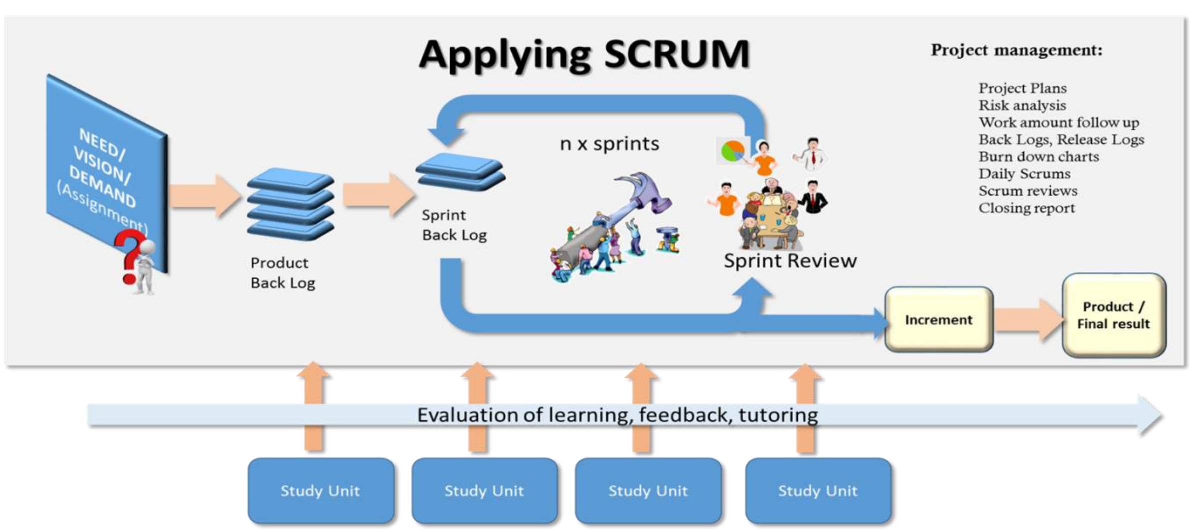

Figure 2. Using SCRUM in integrated learning projects

The organization model is chosen for the learning project, for example, a generic project management and implementation model or one of the agile methods, e.g. SCRUM. SCRUM method is widely used in other Universities as well. For example, Turku University of Applied Sciences (Kontio et al. (2017)), is using it in teaching. The teacher team makes decisions on, among other things, the times to start and end, the number of mutual reviews, ways of guidance, etc. The timing for each of the courses that support the project is defined.

Students feedback about these projects followed the experiences according to Kontio et al. (2017):

- Projects are a good way to learn
- Working with stakeholders is valuable and good training
- Projects support understanding the lectures
- Working with real-world projects support to develop professional skills
- Some projects are too demanding

CASE STUDIES

CASE 1 - Smart Cabin

The basics of project management are studied during the first year's seasonal project. The first year's spring project is called Smart Cabin, in which the students implement demos of automated houses. The demos are presented for surrogate clients at the end of the project. Study modules integrated to the seasonal project are presented in figure 3.

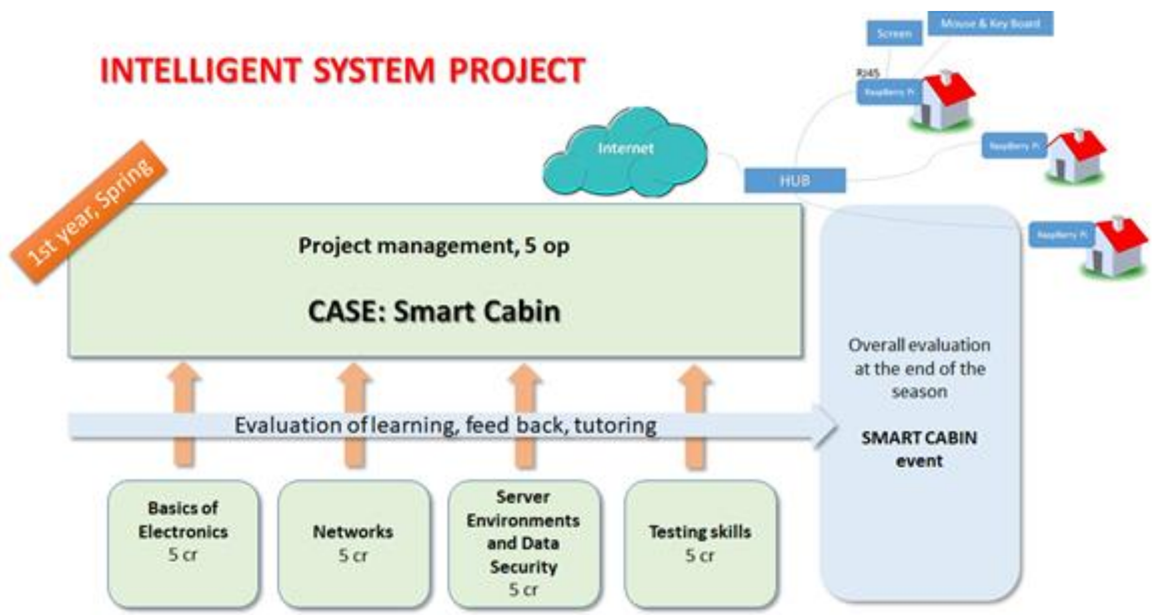

Figure 3. The first year's seasonal project and the integrated study modules.

Automated houses are implemented using technologies compatible with Raspberry Pi computers. The system should be able to measure sensor information, it should be monitored via a website, and the potential security risks should be assessed. The system should be disguised as miniature houses. The houses are combined to an exposition and they were all connected to a common network (Figure 4).

Figure 4. Exposition of miniature automated houses

CASE 2 - UI for eSLED

The third year's seasonal project is organized in co-operation with the R&D personnel, in which case the students are gain experience on working with a customer. On the other hand, the results of the project will also benefit the client, as the students are working on a real-life problem.

In spring 2016, the third year's seasonal project was provided by the Arctic Power Laboratory, the Center of Cold Climate Engineering of Lapland University of Applied Sciences. Arctic Power requested for an implementation of a control and measure system for an electronic snowmobile, and a mobile UI (Figure 5). More detailed description of the previous development project can be found in the publication of Kantola et al (Kantola et al, 2014)

The target of the UI for the eSLED project was develop a user interface to control and monitor systems of the electric snowmobile. Interface visualize real-time dashboard to driving control. For later analysis, there also should be a possibility to send data from the vehicle from terrain to database through telecommunication channel e.g. 3G mobile phones or by using GPRS.

Figure 5. The third year's students working on the eSLED by K. Karlsson.

Measurement technology project - UI for eSled combines mobile technology-oriented course to practical lab course where students must design all layers which are needed to implement measurements to monitor and control of the complicated electric driven vehicle.

Figure 6. presents integrated study model of 3rd-year students project related to the seasonal project. All 5 ECTS was a part of the project. Individual study units were evaluated separately. The project was evaluated end of the season by teaching team, which was consist teachers of individual study units.

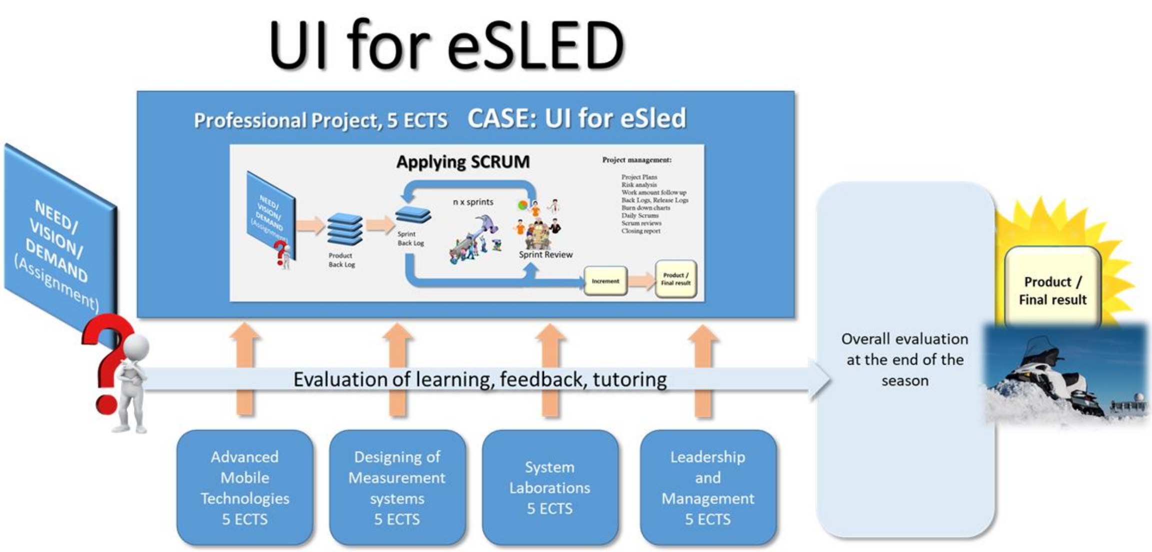

Figure 6. The integrated study modules in spring 2016.

The project management method of seasonal projects during the second and third year is SCRUM. The project is divided into phases, which are called sprints in SCRUM. Each sprint is reviewed by a team consisting of teachers and R&D employees, which act as customer representatives in the project. The duration of a spring is approximately 2-3 weeks. Student groups present a demo of the sprint's results in half-hour Sprint Review sessions. The teacher team consists of the teachers responsible for the integrated study modules. The learning requirements of each study module are reviewed by the results of the project. During the reviews, students receive feedback and guidance and they can gain experience in working with a customer.

DTS – Digital Trekking Services

In spring 2017, the seasonal project was provided by a project called LuontoRovaniemi, which is organized in cooperation of Arctic Power laboratory and software engineering laboratory PLAB. The city of Rovaniemi and Metsähallitus (*Finnish Administration of Forests*) were also involved in the project.
The goal of the project was to create a brand for the eco-tourism in Rovaniemi area and to bring up the therapeutic elements and well-being effects of the arctic nature though branding and electronic marketing. The goal of the students' seasonal project was to innovate mobile applications for e.g. maintenance and development of trekking trail network.
In spring 2017, the third year's sixth semester contained the study modules presented in figure 7. The study modules were integrated into a study module called Professional Project.

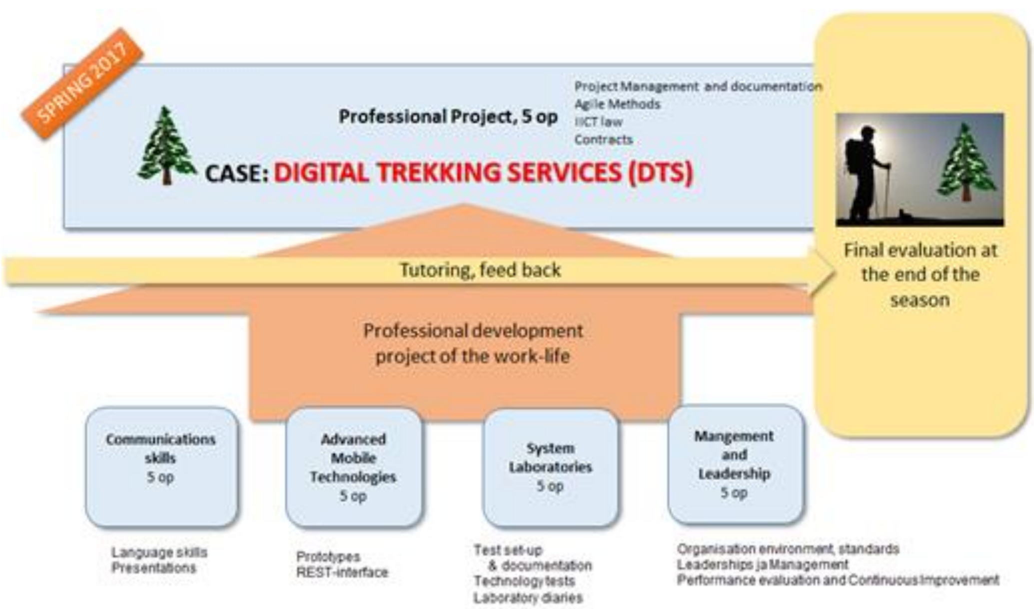

Figure 7. The integrated study modules in spring 2017.

Student presented the prototypes at a fair organized by the degree programme. The public of the fair consisted of students, the personnel of the degree programme and the R&D team. Representatives of Rovaniemi city and Metsähallitus were also invited to join the fair as special guests.

CONCLUSIONS

Self-evaluation based on CDIO continuous improvement process was done in three phases, 2013, 2015 and 2017 respectively. Special areas of development were chosen as can be seen in Table 1. Principles 5, 9, and 11 were improved in the comparison between 2013 and 2017. Teachers' proficiency in CDIO skills (principle 9) was slightly improved. In addition to the teachers' professional skills, system building skills and process and product skills, the interpersonal skills were improved. The new curriculum of the ICT degree programme contains the CDIO and project-based working method as leading standard. The method will be applied for all future ICT groups intaken. All study units will be integrated into the seasonal projects. The process will be further improved according to the continuous development principles. Next self-evaluation is going to be implemented in the year 2019.

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BIOGRAPHICAL INFORMATION

Tauno Tepsa is a Senior Lecturer in ICT Department at the Lapland University of the Applied Sciences. His main focus is on electronics and embedded systems being responsible for the lecturing of those topics. Continuing research of switch-mode power supplies and embedded electronics and participating in development projects belong to his everyday work.

Maisa Mielikäinen is a Senior Lecturer in ICT Department at the Lapland University of the Applied Sciences. The main focus these days is on teaching the software development, software engineering, and Project Management. She is also in charge of the curriculum development and coordinating the teacher teams.

Juhani Angelva is a Senior Lecturer in Industrial Engineering, Leadership & Management, Engineering Entrepreneurship at the Lapland University of Applied Sciences. His current research focuses on Quality Management and on curriculum development.

Corresponding author

Tauno Tepsa, Senior Lecturer
Lapland University of Applied Sciences
Jokiväylä 11
96300 Rovaniemi, FINLAND
+358-
tauno.tepsa@lapinamk.fi

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CDIO IMPLEMENTATION USING 24/7 WORKING SPACES

Eduardo A. Gerlein, Jairo Alberto Hurtado, Juan Manuel Cruz

Pontificia Universidad Javeriana, Electronics Department, Bogotá Colombia

ABSTRACT

This document discusses the adaptations, reforms, and challenges faced at the Electronics Lab at Universidad Javeriana, in Bogotá-Colombia to provide adequate logistic support to the implementation of the CDIO model to the undergraduate program in Electronics Engineering. These adaptations involved not only the use of spaces, electronic equipment, computers, and availability 24/7 for students and teachers, but also the contribution to students learning in individual and intragroup responsibility, and self-regulation. The paper highlights how a successful implementation of a CDIO curricula have been achieved through some changes in the furniture, spaces for study and workgroup, as well as greater integration of the students while they conduct their academic work.

KEYWORDS

Workspaces, Laboratories, Electronic Equipment, Standard 6.

INTRODUCTION

CDIO standard 6 involves workspaces and laboratories since they are fundamental elements for an appropriate CDIO implementation (CDIO. 2017). The School of Engineering at Pontificia Universidad Javeriana in Bogotá, Colombia, has implemented deep changes in the spaces, use and administration of the Electronics Lab to provide adequate service and logistic support to the new CDIO curriculum in the Electronics Engineering Undergraduate (EEU) program[5] (González et al. 2013). The Electronics Lab is a service unit in charge of providing infrastructure, equipment and logistic support to academic activities offered by the Electronics Department.

The current CDIO curriculum, reform of the EEU program, enacted great challenges that needed to be addressed without increasing the areas and workspaces nor the number of staff members at the Electronics Lab. The CDIO model implies a considerable increase of the experimental and project component of the different subjects within the curricula, which in turn increased the number of lab users. Such changes directly impact the resource

[5] For clarity purposes, EEU can be understood as a five-year bachelor degree in Electrical Engineering.

management available at the Lab for classes and research purposes (Sun, Wen, and Guo 2013).

The policies implemented to address the new requirements of the EEU program are the result of an ongoing strategic planning process which considered the new syllabuses, past experiences reported in the literature (Young et al. 2005), recommendations from teachers, and especially, self-report surveys answered by the students.

This document describes the adaptations, reforms, challenges and projections currently addressed by the Electronics Lab to give the adequate support to the CDIO implementation. These adaptations involved not only the use of space, electronic measurement equipment, computers, and software, available 24/7 for students and teachers, but also the contribution to students learning in individual and intragroup responsibility, independence, practical work, safety rules, punctuality, solidarity, and sense of community. This document also shows how through those changes, group work has been achieved, as well as greater integration of the students while they conducted their work.

Such contributions have been achieved through various models of electronic equipment loan to students, such as equipment assigned to work groups for the class time (2 to 3 hours) and equipment assigned to work groups during the entire academic term (16 weeks, 24/7). Also, there are equipment kits available 24/7 for free use which are self-managed by the students. Such freely use and availability of the equipment is a big difference concerning the equipment loan management policies applied in other universities.

The following section shows a general description of the electronics lab and its infrastructure. Physical infrastructure and number of staff have barely changed since the construction of the engineering building in 1996.

ELECTRONICS LABORATORY

As mentioned, the Electronics Lab is a service unit in charge of providing infrastructure, equipment, and logistic support to several academic activities such as teaching, learning and research. The Lab is open 24/7 all the year around, except during the winter break (three weeks from the middle of December to the first week in January).

In particular, the Electronics lab offers services of workspace assignation, lending of electronic equipment and components, technical advisory, lab experiments design and testing, and short capacitation courses. Student users typically belong to EE, Computer Science, and Musical undergraduate programs, as well as Electronics and Bioengineering Master, and Engineering Ph.D. graduate programs. Moreover, the Electronics Lab provides services of technical support such as printed circuit board (PCB) design, prototyping and high complexity soldering, workspace assignation and personnel hiring for the different projects and research groups ascribed to the Electronics Department. In addition, the Electronics Lab is in charge of acquisition, maintenance, and inventory management of all the electronic equipment belonging to the electronics Department.

Currently, there are ten staff members at the Lab assigned to different roles:

- The Electronics Lab manager in charge of directing and coordinating all the actions towards the correct functioning of the unit, usually a role occupied by a faculty professor.
- One administrative assistant in charge of the purchase processes and administrative support.
- Three storehouse clerks, in charge of user attention, lending of equipment and components, workspace assignment, class logistics, storage and inventory management.
- Four Lab technicians in charge of maintenance of electronic equipment, computers, servers and software licensing, technical support, short capacitation courses, lab experiments design and test and other special services, such as 3D printing, PCB prototyping, and soldering.
- One system administrator in charge of managing, updating and feeding the online platform used for inventory and lending management.

PHYSICAL INFRASTRUCTURE

Currently, the Electronics Lab has an area of approximately 1,200 m^2, covering two floors at the Engineering building, distributed as follows:

- Eight general purpose workspaces with a capacity of a maximum of 15 students or five teams of three students. These workspaces are used by classes with a practical component or for freely work by any student during off-classes. Figure 1 depicts a typical general-purpose workspace during a class.

Figure 1. A general purpose workspace during a class.

- Ten workspaces used by students developing their senior capstone project or their master and doctoral thesis. It is worth mentioning that such workspaces are grouped by topic, hence there could be undergraduate, M.Sc. and Ph.D. students in the same room.
- Six special purpose laboratories covering the areas of automatic control, process control, power electronics, telecommunication networks, biomechanics, and robotics. These laboratories are used mainly to cover the practical component of those related subjects but also are used by some students in their senior capstone projects or thesis that require equipment placed inside these laboratories.
- Three classrooms with a capacity of 24 students, equipped with mobile tables and laptops loaded with specialized software such as circuit simulation, electronic design, electromagnetic design, and signal processing software, Figure 2 shows a picture of such workspaces.

Figure 2. Classroom equipped with laptops

- Three large open areas for group study with movable tables and easy access to floating electric sockets, as shown in Figure 3.

Figure 3. Group Study Areas

Although the areas and distribution seem to be enough to handle an Electronics Engineering program, the School of Electronics has kept the same amount of spaces for the past 20 years. However, the implementation of CDIO modified the instructional models, hence increasing the laboratory components in the majority of the courses within the curriculum. Therefore, the academic services and policies provided by the Electronics Lab have been updated to offer a high degree of flexibility for the users (i.e., students and teachers) and faster response to requirements while keeping equipment and resources in the best conditions.

LABORATORY POLICIES FOR DIFFERENT INSTRUCTIONAL MODELS

As mentioned, the Electronics Lab provides services to the EEU, Computer Science and Musical Studies, and to the graduate programs of Master in Electronics, Master in Bioengineering and the Ph.D. program. Nonetheless, the largest number of users belong to the EEU which has experienced a deep and extensive curricula re-engineering as a result of the adoption of the CDIO principles. This reform sets a new number of courses launched in the first term of 2016. Although the CDIO academic program is still reaching the sophomore year (4^{th} semester), several pilots of the courses have been conducted, tested and refined in subjects over the junior year (i.e., 5^{th} to 6^{th} of the 10-semesters program)

The CDIO model proposes that the different courses offer learning experiences to the students with practical and lab components, e.g., experiments in laboratory and practical engineering projects. The new CDIO EEU program exposes the students to the lab and electronic equipment since their first week at the university. This situation implies an increment on the number of users as well as the number of courses that require the academic services offered by the Lab. Figure 4 presents the number of users and courses since 2013. As shown, the number of users of the Lab remained relatively constant before

2016 but they have been greatly increased since the launch of the CDIO program in that year. From the Lab´s perspective, users are accounted as individuals enrolled in a course which requires academic services from the Lab, e.g., a student that is enrolled in one practical course and another course with a laboratory component, is counted as two different users. A similar situation occurs with the number of courses since they are accounted according to the number of workspaces required, e.g., a course of 24 students that has two different laboratory sessions and requires two workspaces for 12 students each, is counted as two courses. Worth noting that despite these increases the Electronics Lab has not received a major increase in funding, therefore the necessity of reviewing and modifying the lab policies to account for the new requirements driven by the increase in users and courses.

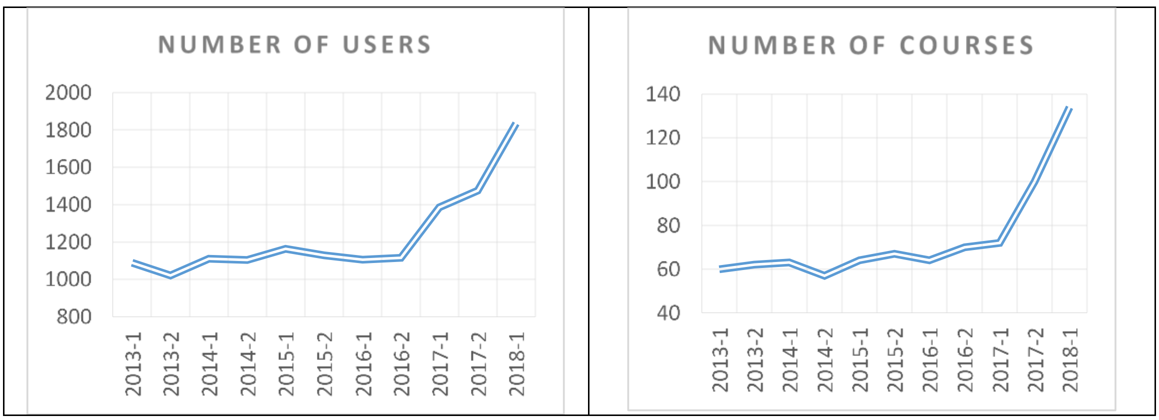

Figure 4. Number of users and courses serviced by the Electronics Lab

The courses of the EEU are offered using four different instructional models, which in turn determines the way that the Electronics Lab fulfill their particular requirements. The first instructional model is the traditional-teaching courses (typically belonging to the previous curriculum). Those courses are taught in classrooms along the University campus and are not typically lab users. Currently, those courses represent about 20% of the total of courses offered by the Electronics Department.

A second instructional model is composed by courses that are mostly theoretical, but the evaluation is performed using a project-based approach. Students in these courses must implement one or several projects during the semester. This model is used in courses such as Embedded Systems Design, Digital Systems Design, First Year Integrated CDIO Project, and Applications of Internet of Things. Those projects are developed in groups of two or three students. In this case, the Electronics Lab provides both development boards and a locker to store their materials to each group of students for the entire semester. Additional equipment must be solicited online and, depending on its availability, lent to students with no requirement of time in advance. Students can work on their projects using any of the eight general purpose workspaces during time frames where classes are not being taught.

The third model corresponds to those courses with a practical component that is used to reinforce or to clarify concepts taught in class. This model is used in subjects such as Fundamentals of Electric Circuits, Analog Electronics, Electronic Devices, Non-Linear Electronics, Control Theory, Dynamical Systems, Signal Processing Laboratory, and

Electronics Instruments and Measurements. Each practical session is described using a laboratory guide where not only the experimental procedure is discussed but also all the equipment and electronic components required are stated. In this case, the Electronics Lab depot clerks have an estimated schedule of all the laboratory sessions at the beginning of the semester. Unforeseen situations may vary the schedule; hence the Electronics Lab is in charge to confirm all practical sessions within a week in advance. The day of the practical session, the depot clerks are in charge of organizing all the required equipment and electronic components, and to transport such materials to the correspondent workspace. At the beginning of the semester it is desirable to program similar practical sessions consecutively in one classroom, so it is possible to organize the same equipment set for a whole day and located it in one particular workspace. Nevertheless, this is not always the case. Thus, the organization and transportation of equipment is a permanent task of the Lab. Neither students nor teachers have to make reservations for their practical sessions. The Lab is informed in advance of the schedule and the organization of the equipment for a whole day of practical sessions is performed the day before. Lab technicians thoroughly review the experimental guides previously to the session, and if some updates are required, they informed the teachers in due time. Similarly, the technicians may also work together with teachers in the design of particular lab practices or experiments and participate in the elaboration of the written laboratory guides.

The fourth model includes those courses that follow a project-based approach. No theoretical sessions are taught because students reach such courses after completing previous modules that prepare them to develop the proposed projects. Courses in this category are Third and Fifth Year Integrated CDIO Project, Fundamentals of Electronic Design, Analog Design, Non-Linear Design and Senior Capstone Project. In all these cases, each group of students are assigned with a basic equipment set and correspondent probes for the whole semester. Each general purpose cubicle is equipped with shelves used by the students to store their assigned equipment as shown in Figure 5. Similar to the second model, those students that require additional equipment are entitled to make reservations upon availability any time and duration needed. Noteworthy, the Lab staff is not available 24/7, hence there are some time windows to claim the required equipment and components. The students in a group are co-responsible of the assigned equipment. Lending equipment to a group for the entire semester is intended to provide a positive impact in their individual and group responsibility, independence, practical work, safety rules, punctuality, solidarity, and sense of community.

Worth to mention, that the workspaces where the assigned equipment is stored (see Figure 1) are of free access for all students at all times, except when the classes and lab practices are scheduled. During this time, the use of workspaces is unrestricted and unsupervised. The students are not allowed to take or use assigned equipment belonging to other groups. Nevertheless, this policy is not hard enforced. On the contrary, students self-regulate their behavior in this regard. Even though there is a CCTV to cover all the Labs areas, only on rare occasions this system is used to find damaged or missing equipment. Students develop respect for their pairs and leave their assigned devices trusting their classmates and students from other semesters, even when the assigned equipment might overcome the prices of USD$10,000. The first week of classes, students are informed regarding house rules and safety norms. Due to the fact that they will be working without supervision most of the time, students are responsible for their safety as well as their classmates'. In case of equipment damage or malfunction, students are encouraged to present a report to the Lab personnel. Most cases are related to normal use and deterioration. Some damages are the result of misconducts or bad use, and in those cases, students must replace the damaged piece or part. The same level of self-regulation is observed at the PC rooms, where a set of laptops is available at all times without safety attachments to them. Students are not allowed to take the laptops outside the classrooms, but similarly to the case of the equipment, the policy is not hard enforced. Students take responsibility for the caring and good shape of laptops.

Figure 5. Shelves located inside the general purpose cubicles used by the students to store their assigned equipment for the whole semester term.

Finally, the Electronics Lab offers several additional services to all the users. First of all, the Lab is equipped with a set of 3D printers managed by the Lab technicians. 3D printing is a free service for the students and is used for prototyping and final details for the projects in all the subjects. Second, the Lab offers PCB prototyping, soldering paste delivery and high complexity soldering. PCB prototyping and soldering paste delivery are performed using computer-assisted machines for such tasks. In these cases, students must bring both a blank circuit board to be printed and the components to be placed.

The Electronics Lab is open 24/7 all the year around. Such policy does not mean that the clerks are available the entire night lending equipment. The Lab has disposed a set of work banks and probes available for unrestricted use at any time. The unrestricted equipment is located outside the classrooms in the hallway, and any student that needs one or several pieces of equipment is encouraged to use them for the time needed. Worth to mention, that the unrestricted equipment is enough to perform most of the measures required. Students put back the equipment on the respective shelves after finishing their work. Periodic preventive maintenance is performed on this equipment to calibrate it and maintain it in the best possible conditions. As the reader may notice, both, the unrestricted and assigned equipment, is stored on shelves outside the depot at the Lab. The assigned equipment is used only by the groups entitled to it. The unrestricted equipment must be correctly stored after use. These rules are informed at the beginning of the semester and enforced during the academic term. Students recognize the privileges given to them in this regard, and they have formed a culture of self-regulation and responsibility evidenced by the scarcity of reports of equipment damaged, missing o deteriorated. The unrestricted equipment, as well as the permanent assigned banks, were conceived as an experimental policy to address the increase of students' work requirements during nights and weekends. The policy became permanent after assessing its positive impact, mentioned by both, teachers and students, in surveys and the suggestion box.

ELECTRONICS LAB POLICIES

Since its origins, the Electronics lab has a sustained policy of renewing, maintain and increase the electronic equipment. Such policy was reinforced during the past five years, knowing the interest and posterior decision of adopting the CDIO initiative. Without an increase in budget (besides the inflation-based increase) the Electronics Lab has been making efforts to acquire sufficient amount of equipment to fulfill the increment of users and courses observed in Figure 4. The amount of the inventory in the Lab must fulfill those for unrestricted use, permanent loan, and laboratory practices. The Electronics Lab provided services to about 450 students daily from 6:30 a.m. to 8:00 p.m. and its facilities remain open during nights and weekends.

Lending equipment can be as restrictive as decided. As opposed to that, the policies implemented by the Lab have been oriented to offer a high degree of flexibility, with no restrictive times for reserving and soliciting equipment. Also, such policies aimed to reduce the response time to last minute requirements. In turn, a higher degree of flexibility in the lending process implies more complex management. To keep track of multiple reservations, lends, and inventory, the Electronics Lab decided to adopt an online service. In this case, the platform WebCheckout was selected to aid those processes. A systematized platform is mandatory to exert close control of the equipment that is currently outside the storage depot. Reservations are made online using computers or mobile devices. Lends are announced via e-mail and controlled using a public dashboard displayed on TV screens.

In turn, each equipment is monitored using the platform that allows to keep track of usage statistics, maintenance, and to set specific lending policies that restrict some equipment to a particular group of students. Statistics of usage are reviewed periodically to plan the purchases of those devices that are mostly reserved. Such statistics are also used to dispose of obsolete elements. One technician is assigned permanently to the management of the platform that includes setting-up the lending policies, feed the platform with new equipment (including its main characteristics, a photograph, a digital version of the manual, and information about availability). For internal use, additional information is included such as maintenance rounds and observations. An online system is the core support of an operation of such magnitude as the executed daily by the Electronics Lab.

CONCLUSIONS

An undergraduate program that incorporates the CDIO model supposes great efforts at the academic level and curriculum design. However, being that true, this is only a fraction of the challenges that an academic institution must address to provide the adequate infrastructure to support a program based on experimental approaches and projects. This paper has discussed how the management policies of the Electronics Lab of the Pontificia Universidad Javeriana, at Bogotá-Colombia, has been modified after the launch, in 2016, of a new CDIO-based undergraduate program in Electronics Engineering.

The new CDIO program in Electronics Engineering exposes the students to the lab at early stages in the process which in turn, implied an increment on about 60% of the number of users as well as an about 100% increase in the number of courses that require Lab services. The Electronics lab has addressed those requirements by changing policies aimed to increase the degree of flexibility in the lending process related to the four instructional models. In summary, such policies are equipment lent to individual groups during class schedule, laboratory equipment assignation during the entire academic semester to each group and equipment available 24/7 with self-management and self-regulation by the students. Knowing that the impact of policy changes in academic institutions could have a long delay, the latter two policies were implemented in 2012 and 2015 as a preparation for the expected increase in the number of users and courses.

With the model of work and loan of equipment that is held in the electronics lab, students must, in addition to fulfilling their academic obligations, implement their responsibility, both individually and collectively with solidarity and self-management. Although the institutional culture in the previous curriculum was also oriented to increase such values, the policy changes in response to the new requirements of the CDIO program reinforces such values. Otherwise, it will be highly difficult to accommodate to the new requirements without a substantial increase in funding and infrastructure.

The CDIO program was launched in 2016; the 2016 cohort is currently in the second year of five. Future challenges will be oriented to face more complex integrated projects such as the ones proposed for the third through fourth year of the program.

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BIOGRAPHICAL INFORMATION

Eduardo A. Gerlein, Ph. D. is an assistant professor at Pontificia Universidad Javeriana Bogota, Colombia, at Electronics Department. Chief of Electronics Lab.

Jairo A. Hurtado**,** Ph. D. is an associate professor at Pontificia Universidad Javeriana Bogota, Colombia, at Electronics Department. He was Chair of Electronics Engineering Program and he has working in different projects to get a better process learning in his students.

Juan M. Cruz, M.Ed. is an assistant professor, at Electronics Department. He was the chair of Electronics Engineering undergraduate Program at Pontificia Universidad Javeriana (2008-2012), laboratory manager and the program coordinator of Engineering Education Diploma at Pontificia Universidad Javeriana. Currently, he is a Ph.D. candidate in Engineering Education at Virginia Tech, USA.

Corresponding author

Dr. Jairo A. Hurtado
Calle 40 No. 5-50. Ed. José Gabriel Maldonado S.J.
Pontificia Universidad Javeriana
Bogotá, Colombia
57-1-3208320 Ext 5327
jhurtado@javeriana.edu.co

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THE PEDAGOGICAL DEVELOPERS INITIATIVE – SUSTAINABLE IMPACT OR FALLING INTO OBLIVION?

Björn Kjellgren, Hans Havtun, Lasse Wingård

School of Industrial Engineering and Management (ITM)

Magnus Andersson

School of Engineering Sciences (SCI)

Björn Hedin

School of Electrical Engineering and Computer Science (EECS)

Niclas Hjelm

School of Engineering Sciences in Chemistry, Biotechnology and Health (CBH)

KTH Royal Institute of Technology
SE 100 44 Stockholm, Sweden

Anders Berglund

School of Innovation, Design and Engineering (IDT)

Mälardalen University
SE 631 05 Eskilstuna, Sweden

ABSTRACT

Between 2014-16, KTH Royal Institute of Technology set aside considerable resources in its biggest pedagogical project to date, the Pedagogical Developers Initiative. The project has been continuously reported on at recent CDIO conferences. While aimed primarily at CDIO Standard 10, enhancement of faculty teaching competence, the project managed, by design as much as through accident, to strengthen many CDIO standards and syllabus items. With the conclusion of the project, the constructive practices and ideas that emerged from the initiative were meant to be incorporated into the regular operations of the university, a task that was delegated to each of KTH's ten schools. However, even though KTH officially labelled the project a success, the schools have taken a non-uniform approach to this endeavour, as they indeed had done to the project as a whole during its duration. Following up on our earlier reports, and primarily using data from interviews and our own observations, the paper looks at which of the initiative's ideas and practices have survived the end of the project, in what forms, by what means, and what insights and lessons one can draw from this

when designing mechanisms for continuous and sustainable improvement of pedagogical practices at a technical university.

KEYWORDS

faculty development, educational development, educational leadership, CDIO Standard 10

INTRODUCTION

KTH Royal Institute of Technology carried out a pedagogical initiative during 2014-2016 to increase pedagogical competence among faculty and to build a culture of continuous pedagogical development. The initiative was strongly related to CDIO Standard 10, enhancement of faculty teaching competence, and inspired by the Carl Wieman Science Education Initiative (CWSEI) (Wieman et al. 2010) although the design at KTH differed in important ways. Following a call in late 2013, 24 pedagogical developers (PD) were appointed by their respective deans of schools. The PDs should function as local change agents, creating and facilitating communities of practice (Wenger 1998). In contrast to the CWSEI, where designated educational developers assisted individual teachers transform their courses, the Pedagogical Developers Initiative (PDI) was a process to simultaneously promote pedagogical development at all schools at KTH and to inspire teachers to increase their pedagogical knowledge. Hence, the PDI can be seen as an innovative attempt to promote pedagogical change through a bottom-up process.

The PDs were both engaged in local pedagogical projects at their respective schools and in a joint process to support pedagogical development on a university-wide scale. During 2014, the common project was to establish communities of practice among KTH's faculty, mainly by developing a method for course analysis that supported course development (Berglund et al. 2015). During the first year, it was also recognised (Berglund et al. 2015) that the activities within the PDI covered a large number of the CDIO standards and were not entirely devoted to CDIO Standard 10. In 2015 the common project was to develop and offer a set of pedagogical workshops targeted at all teachers at KTH (Berglund et al. 2015). In the final year of the project, the PDs refined the course analysis process as well as the workshops and took actions to increase their use. The PDs also compiled a list of proposals to promote further pedagogical development at KTH to the KTH education committee (Berglund et al. 2016). After the end of the initiative, the responsibility for pedagogical development was transferred to KTH's ten schools. In this paper we will follow up what has happened after that and try to draw some conclusions about what to consider when trying to engage in a similar endeavour.

In brief, the legacy of the initiative, one year after its conclusion, can be described as mixed. The two common projects, the course analysis process and the pedagogical workshops, have survived and are now in the custody of the Unit for Higher Education Research and Development (HERD), but still mainly staffed by former PDs. Many of the short-term recommendations for pedagogical development put forward in the final report of the PDs have been taken up by KTH top management and are in the process of implementation. Most of the PDs have also continued to work with educational development. However, when looking at local projects run by individual PDs at the different schools, the situation is more complicated. Most schools lacked plans for how to sustain the many small-scale initiatives, and only a minority of projects are still ongoing.

METHODOLOGY

Our follow-up assessment had two foci. The first was the outcomes of the initiative in terms of what had happened with its many sub-projects, with the teachers involved as PDs, and with their suggestions for actions on pedagogical matters to the university management at the conclusion of the project. In a few cases, the projects have been implemented in such a way as to leave official documents, but for most of them we have relied on the former PDs' accounts of the trajectories of projects and of themselves. The second focus was the memory of the initiative as recollected by a limited number of stakeholders within the administration: the vice dean of faculty, the directors of first and second cycle education at the (then) 10 schools of KTH, as well as a few other persons that we had reason to believe could have important insights in the initiative. In total we conducted about 20 semi-structured interviews, varying in time from about 45 min to two hours. These interviews had a core consisting of four questions for the schools' directors of studies, and three questions for the PDs, allowing time for follow-up questions, clarifications and the following of whatever train of thoughts that could emerge in the interview situation.

When interviewing the schools' directors of first and second cycle education, we made a point of not interviewing the directors that we ourselves had worked under in a school when possible. This was not something that we could do when interviewing the PDs, since most of us had worked together at one point or other during the project. Since the authors of this paper constituted a substantial part of the more active group of the PDs, it was necessary to include also our own recollections and observations. This was, however, not done by interviewing each other but by writing down our observations and recollections directly in the text, subjecting ourselves to the peer review and follow-up questions of our co-authors during the process of writing the paper.

FOLLOW-UPS

In this part of the paper, we report first in some detail on the fate of the two common projects that the PDs worked with during the first and second year. Then we report briefly about what has happened to the many projects carried out by individual or smaller groups of PDs. Finally we describe the completion of the project and the effort to hand over the project both to KTH and to the ten schools of KTH.

The course analysis process

Although originally developed as a student learning experience questionnaire (LEQ) that should support collegial pedagogical discussions among faculty members, it was realised that this concept could be put into a larger context as seen in Fig. 1. Here, LEQ or other methods are used as analytical tools in a cyclic improvement process, which also include collegial course analysis meetings (and possible students' analysis meetings) in order to improve courses (Borglund et al. 2017). This process facilitates the exchange of experience and pedagogical ideas among teachers. In 2017 the president of KTH decided on new regulations concerning course evaluation and analysis highlighting collegial experience exchange as an important required element. An important reason behind this decision was the natural way students could be included in the process, either through student's analysis meeting or through participation in collegial meetings. In order to separate the questionnaire developed within the project, LEQ, from the process, the name of the process was changed to "systematic course analysis" (SCA) in late 2017.

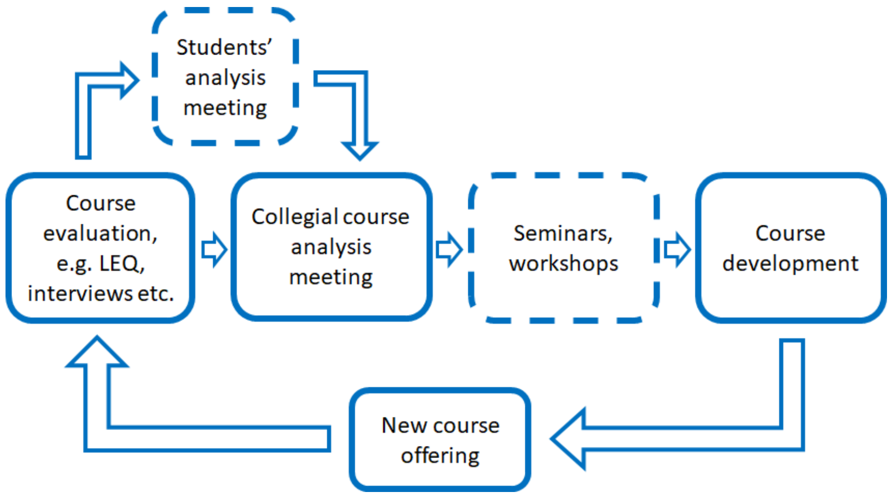

Figure 1: The systematic course analysis (SCA) process.

The LEQ and the SCA process have been used to a fairly high degree at KTH. It was, however, not introduced by all PDs from the beginning and as a result, it was not spread to all of KTH's schools initially. In later years, with technical systems in place to facilitate the dissemination and analyses of the questionnaire, the process has spread to all schools and between January 2014 and November 2017, more than 1400 course offerings have used the LEQ for course evaluation. In total, over 33 000 questionnaires have been filled in by students. After the PDI, the simplicity of using the LEQ and the analysis tool is still attractive for many teachers, while the course analysis meetings are only continued at a few schools as there is no longer a PD responsible for organising them.

Pedagogical workshops

The pedagogical workshops, developed by the PD group in 2015 (Berglund et al. 2016) are since 2016 a part of KTH's basic course in teaching and learning for teachers. Although the PDI was finished in 2016, the workshops are still run by former PDs. The scheduling of the workshops was in the beginning of 2018 taken over by the Unit for Higher Education Research and Development (which is responsible for giving the course). This is a strong indication that the workshops will remain. The workshops are open to all KTH teachers, but only a handful of teachers not participating in the course participate. The workshops are also given on demand (for example when a school organises a pedagogical seminar), which has happened on a few occasions. Our interviews show that this information has not reached some of the schools' directors of first and second cycle education, a minority of the programme directors and only a few of the teachers. Some of the workshops have been given in international settings, including *Assessment methods*, *Intended learning outcomes and the course plan*, as well as *Designing courses for motivation*, which were all given during an Erasmus+ higher education mobility exchange to Trinity College Dublin, Ireland, in January 2017. The workshop *Designing courses for motivation* has also been given at the CDIO European regional meeting 2017, as well as at the 13th international CDIO conference in Calgary, Canada.

Other projects

The projects mentioned above were activities that most PDs had in common and often worked together with, but the initiative also involved a number of other activities and in Table 1 we have listed most of these without going into details, and indicated the target group or scope for the activity, the initiator, and the present status after the conclusion of the initiative.

Table 1. Status of other projects at different levels, early 2018

PD = pedagogical developer, DE = director of first and second cycle education, PDir = programme director.

Target group	PD activity (number of schools involved)	Initiated by	Current status
Individual teachers	Support for course development (2) E-learning, "flipped classroom" (3) E-learning, clickers (2) E-learning, automatically corrected assignments (1)	DE PD PD, DE PD, DE	Discontinued Implemented & cont. Implemented & cont. Continued
Individual educational leaders	Progression within study programmes (1) Develop new courses (3) Progression within study programmes (1)	DE PDir PDir	Implemented Implemented Continued
Teacher teams	Pedagogical interest groups (1) Changes in mathematics education (1) Equality and diversity (1) Audit course development work (1)	PD PD PD PD	Discontinued Implemented in part Finished Discontinued
Department	Pedagogical seminars or lunch meetings (3) Annual pedagogical day (2) Programme development (2) E-learning projects (4) Setting up international agreements (1) Establishing Pedagogical council at school level (1)	PD PD DE DE PD PD	Continued Continued Implemented Implemented & cont. Implemented in part Not implemented
University	Courses in teaching and learning in higher education New guidelines for course syllabuses and course information Certificate of Global Competence (for students)	PD PD, Univ. Admin. PD	Established & cont. Implemented in part, continued Established & cont.

Completion and handover

Towards the end of the project, the schools were formally informed that they were expected to take over the responsibility for future pedagogic development and to incorporate the work done by the PDs in their usual budget. Due to their relative independence, it was up to the different schools to decide how they wanted to evaluate what parts of the PD activities to be retained. The only thing made clear was that there would be no central funding for the continuation of the project's activities. This was also one of the rationales behind the early summation of the PDI in a final report to the KTH education committee in May 2016, where the PDs suggested a number of actions for improving and facilitating pedagogic development both in a short and in a long term perspective. As seen in Table 2, the short-term actions are mostly on the way of being realised, while the long-term strategic decisions suggested by the PDs are not considered at the moment. These included e.g., suggestions for a development oriented pedagogical programme, a personal pedagogical development plan for every faculty member, a pedagogical academy, facilitating of university-encompassing research in teaching and learning, a pedagogical forum and an increased status for performing pedagogical development.

Table 2: A summary of the status of the PDs' proposals for actions to facilitate pedagogical development at KTH.

Suggested action	**Current status**
Decide on collegial course analysis meetings and dedicate time for this in the schedule.	Policy decision taken, not yet in schedule.
Quality assessment of course plans.	Will become part of quality assurance system.
Create a pedagogical council at each KTH school.	A central council for pedagogical development is established.
Create a follow-up process for courses that are not working properly.	Will become part of quality assurance system.
Ensure that course analyses are made for all courses.	Improved procedures. Linked to economy at one school.
Create an archive where course analyses and pedagogical development can be followed.	Decision taken, archive created and under development.
Use measurable goals in the pedagogic development plans for each school.	Not yet implemented.
Ensure that all courses should have a more standardised course PM, which also includes pedagogical approaches.	Administrative support is under development.
Develop a process for collegial programme development.	Under discussion.
Create clear programme goals for each programme and link them to course goals.	Will become part of quality assurance system.

COMMON AND DIVERGING VIEWS

We will now discuss some of the common and diverging views that we have found during the interviews. Since the interview material is rather extensive, we will concentrate on a few common and central themes that occurred in several of the interviews.

Project organisation and management

Almost unanimously, the interviewees have mentioned the lack of a clear project organisation and management, from the start and throughout the project duration. There was no clear organisation for setting up and following up on requirements, nor any well-defined receiver of results. Thus, the expectations from different organisational units varied, with some PDs being given explicit tasks to carry out for the school, whereas other schools took the stance that, as there was central financing for the project, the PDs of the school could work with any task they found interesting.

One interviewee from the KTH administrations office meant that there should have been a project coordinator appointed at each school, who could have followed up on work and received results. The vice dean of faculty admitted when interviewed that he had expected the schools to follow up and request status reports from its PDs, as the PDs were formally appointed by the dean of each school.

The new role meant that there was some confusion about the responsibilities for pedagogical issues between the PDs, the DEs, and the programme directors. In the interviews, this was pointed out as one possible reason for the lack of management of the PDs from the schools – the schools did not know what kind of tasks to give to the PDs. One of the interviewees expressed it as: "The viewpoint of the DE was that it is more important that something happens, than what specifically happened."

Results of the work

The president of KTH, reportedly said "I am impressed" after receiving the final report of the PDs. The vice dean of faculty commented the statement: "He does not say that often." The vice dean himself stated in his interview that: "When it comes to the results of the PDI, I can see a lot of ripple effects that are probably not visible to everyone."

In the interviews with the schools' directors of first and second cycle education, some of them said that the deans of their schools thought that the focus of the project was not the right one, and that they were dissatisfied with the results. The DE group, on the contrary, had expressed that it was an advantage that the PDs were given the freedom to work with tasks that were of interest and importance to themselves. One DE expressed it as: "The result of the PDI was rather good, in spite of the [lack of] management of the PDs."

Pros and cons that were brought forward in the interviews include:

+ The pedagogical competence has been spread outside the group of professional educational developers at the ECE school.
+ The PDI did well by highlighting teaching, more than research.
+ The project has led to better cooperation between teachers and university administration, and its results have been valuable input in the development of a quality assurance system for KTH.
- The local PD projects are not known to other schools. The results have little impact outside the local environment.
- Status and recognition of the PDs among teachers was not clear, in particular if the PDs did not simultaneously have other formal roles.
- Many proposals are dependent on other resources within KTH, which makes it difficult to allocate resources for development.

Personal development and careers of the pedagogical developers

Nearly all PDs mentioned that the PDI had been personally important to them and had helped them develop their own pedagogical thinking. A few of them also explicitly compared it to a pedagogical trainee programme. On the negative side, one PD mentioned that he had lost some contact with his research group, which he considered bad for his career. Looking at the original group of 24 PDs, by early 2018 seven have left KTH, while 13 hold positions at KTH through which they are able to lead pedagogical development or influence decisions to that end. Five of these PDs had such positions already when the PDI started and eight PDs have been appointed new pedagogical leadership positions, such as directors of studies, programme directors, directors of first and second cycle education of a school, or members of KTH's education committee. It would seem as KTH has been able to take care of the personal competence that has been built up within the PD group in a constructive way.

CONCLUSIONS AND DISCUSSION

As noted there existed quite diverging views within the KTH leadership about the PDI and how it should have been managed already from the beginning. Likewise, the interest in the initiative, including how the emerged practices should be incorporated in regular school work after the initiative, varied considerably, from enthusiasm to scepticism or mild uninterest. As a result, PDs at different schools have been working under very different conditions. Some were quite steered in their activities while others were more or less free to work with things they thought should contribute to pedagogical development at KTH. Also, the PDs had to spend energy trying to handle the consequences of the unclear leadership, which was an inefficient use of their time and which delayed the outcomes of the project. The unclear leadership also explains the difficulties and the lack of general strategies when the KTH schools were supposed to take over the responsibility for the activities. From a change management perspective (Kotter, 1995, Mento et al. 2013), this means that one of the basic steps in a successful change process, defining the strategy for the change process itself, was unclear from the beginning. In a sense this ensured that the project doubly impossible: impossible to succeed and impossible to fail.

Under such circumstances, one may perhaps have guessed that all activities should have died out after the official completion in late 2016. However, this seems not to be the case - instead it seems as pedagogical activities are growing stronger, perhaps a benefit of the project's inability to fail. Many of the former PDs have been chosen for educational leadership positions, where they have the formal authority to implement change. Having worked with the faculty during their time as PDs, they can combine their leadership position with a deep understanding on how the faculty react to change. Hence, the PDI can in retrospective be seen as a de facto trainee programme for future educational leaders, albeit an unintentional one. While the support and interest from the schools varied, the PDI could always count on the support of the KTH top management. They were also impressed by the results coming out from the PDI (despite the delay in the start-up phase) and have since created thematic discussion groups involving pedagogic leaders of more traditional cut, student representatives and administration, in order to discuss and solve university-encompassing pedagogical issues. This will hopefully create new momentum in the university-wide change process, something that was somewhat lost when the PDI ended.

Is it possible from our experiences to give some advice to other institutions that want to do something similar? Perhaps. All universities are in some way or other different from the others, and, as we have seen, there also exists large differences between different schools and departments of a single university. Hence, a method used at one place can seldom be transferred to another place and expected to work in the same way. Having said that, we believe some insight can still be gained from our experiences.

Developing tools and processes that facilitate faculty discussions around pedagogical issues are probably a key component in promoting faculty-wide pedagogical development. The reason for this is quite simple – faculty members are seldom expected to be experts in pedagogics and they have usually very little time available for pedagogical development, especially if this is not rewarded within the university promotion system. This points towards the necessity of lowering the barriers and introducing time-efficient tools (e.g., LEQ) and processes (e.g., SCA), introduce teachers to important pedagogical concepts in short time (e.g., through workshops), create internal rules and resources that promote and facilitates pedagogical development, and create efficient teacher teams that can work collaboratively towards common goals.

In the final analysis, one must also strike a compromise between the rigor of good project management and planning, and the possibility of good things only emerging if not aimed for. As Cohen (1992) puts it: “There is a crack, a crack in everything. That’s how the light gets in.”

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BIOGRAPHICAL INFORMATION

Magnus Andersson is an Associate Professor at the School of Engineering Sciences (SCI) at KTH, and Programme Director for the Master's Programme in Engineering Physics. He has a PhD in Material Physics and has been involved in teaching and learning activities since 1990. He has also been involved in pedagogic research.

Anders Berglund is an Associate Professor at the School of Innovation, Design and Engineering (IDT) at Mälardalen University. He was previously an Assistant Professor at the School of Industrial Engineering and Technology (ITM) at KTH. He holds a PhD in Machine Design and has been involved in promoting CDIO skills related to entrepreneurship and innovation together with other academic teaching and learning activities since 2003.

Hans Havtun is an Associate Professor at the School of Industrial Engineering and Management (ITM) at KTH. He has a PhD in Energy Technology and has been active as a teacher in higher education since 1995. He is the director of the Energy and Environment BSc and MSc program, director of the SCA process, and a member of the council for pedagogical development at KTH.

Björn Hedin is a Lecturer at the School of Electrical Engineering and Computer Science (EECS) at KTH. He has a PhD in Media Technology and has been involved in teaching and learning activities since 1998. He is a member of the research group on Technology Enhanced Learning (TEL), and is vice director of the Master's programme in Media Technology.

Niclas Hjelm is a Lecturer at the School of Engineering Sciences in Chemistry, Biotechnology and Health (CBH) at KTH. He has a degree in Engineering Physics and has been involved in teaching and learning activities since 1998. Besides teaching students, he is currently involved in pedagogical courses for KTH faculty.

Björn Kjellgren is an Associate Professor at the School of Industrial Engineering and Management (ITM) at KTH. He has a PhD in Sinology, has previously worked as a researcher in Social Anthropology, and has been involved in teaching and learning activities since 1994. Presently, he works as Director of Studies, and as Programme Director for two Bridging Programmes for Architects and Engineers with Foreign Qualifications.

Lasse Wingård is an Associate Professor at the School of Industrial Engineering and Management (ITM) at KTH and the Director of undergraduate and graduate studies at the Department of Production Engineering. He holds a licentiate degree in Computer systems for design and manufacturing. He has been working primarily with education for the last 25 years.

Corresponding author

Björn Kjellgren
Dept. of Learning in Engineering Sciences
ITM School
KTH Royal Institute of Technology
Teknikringen 14, 100 44 Stockholm
+46 (8) 790 61 25
bjoern@kth.se

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ADD-ON CERTIFICATE IN GLOBAL COMPETENCE: A PRAGMATIC ANSWER TO A CHALLENGING QUESTION

Björn Kjellgren, Elizabeth Keller, Yoko Takau-Drobin

Department of Learning in Engineering Sciences, ITM, KTH Royal Institute of Technology

ABSTRACT

This paper describes and evaluates a university-wide extracurricular 'Certificate of Global Competence' introduced at KTH Royal Institute of Technology in 2016 as a means to strengthen engineering education with content seen as both very important and hard to fit into existing programmes. Engineering graduates are expected to have the necessary knowledge, skills and attitudes to work effectively and ethically in environments characterised by cultural and social diversity. Going from these demands to educational programmes that integrate the teaching of global competence in true CDIO fashion has, however, proven to be an overwhelming task for many universities. Consequently, most HE institutions seem satisfied with measuring internationalisation using superficial but easily quantifiable data such as the number of international students or the number of exchange students, and KTH is an example of this trend. Students are encouraged to prepare for a global labour market, but their engineering programmes are highly restrictive and leave little or no room for studies of subjects outside the perceived core competencies of their professions. International students at KTH are similarly forced to cope on their own, usually resulting in having them spend most of their free time with other international students. To address this problem, KTH decided to establish the 'Certificate of Global Competence' comprising two elective courses and one study period abroad. The main idea has been to give students the opportunity to equip themselves with essential knowledge, skills and attitudes to function well in intercultural contexts even though they may not be given enough freedom in their programmes. Acknowledging the increasing importance of global competency, we argue that these skills ought to be more saliently described among the desired attributes of graduating engineers in future versions of the CDIO Syllabus.

KEYWORDS

Internationalisation, Global competence, Communication, CDIO Syllabus sections 2 and 3, CDIO Standards 2, 3, 7, 8.

GLOBAL AND LOCAL CHALLENGES

Globalisation has set a number of challenges and opportunities for higher education. Corporate leaders, as well as society at large, require our graduates to have the necessary knowledge, skills and attitudes to work effectively and ethically in environments characterised by cultural and social diversity (e.g. Downey et al. 2006, Diamond et al. 2011). With the inclusion of global citizenship and global competence in UN's Sustainable Development Goals for Education (UN 2015),[6] these requirements are certainly not limited to engineering education, but should perhaps be seen as extra important given the assurances of engineering to remedy some of the problems of globalisation.

The CDIO Initiative has long recognised the need for graduating engineers to interact in an informed way within an ever-changing and evolving engineering field (Crawley 2001). The present CDIO Syllabus also includes relevant skills in sections 2 (Personal and professional skills and attributes), and 3 (Interpersonal skills: teamwork and communication), even though they are not explicitly connected to cultural diversity. However, it has also been noted by members of the CDIO community, e.g., Carlsson et al. (2010) and Hoffman & Christensen (2011), that the actual integration of engineering skills and cultural aspects of engineering poses a challenge to most programme directors and teachers. The gap between what is asked from graduating engineers and what is actually delivered through their education seems indeed to be a salient example of what the CDIO Initiative considered when stating that 'engineering education and real-world demands on engineers have in recent years drifted apart' (CDIO Vision).

We do not mean to suggest that universities are doing nothing. On the contrary, larger universities have made internationalisation one of their key concerns. There are a number of incitements for this, for example, the drive to attract talents, fee-paying students, and proactively work on indicators of influential ranking lists. Regardless of the motives, there is often a genuine will to improve education by accommodating new demands. It is, however, difficult to move from the requests and strivings to the development of educational programmes that successfully integrate the teaching of global competence in true CDIO fashion,[7] including the development of structures and routines needed for a 'comprehensive internationalisation' (Hudzik & McCarthy 2012). In the end, most HE institutions seem satisfied to measure internationalisation by using superficial but easily quantifiable data such as the number of international students or the number of incoming and outgoing exchange students. For this reason, HEI tend to allocate resources and put energy into activities that boost these numbers, while less easily measurable dimensions of internationalisation are left unattended. Despite evidence to the contrary, the students' acquisition of global competency is often expected to happen spontaneously in a setting with people from many cultures, be it at home or abroad (Spencer-Oatey 2015).

KTH Royal Institute of Technology has followed the above-mentioned measuring approach as well. Swedish students have been officially encouraged to prepare for a global labour market but their restrictive programme syllabi leave little or no room for studies of subjects outside the perceived core competencies of their engineering professions. International students at KTH are similarly left to do as they please, usually resulting in them spending most of their free time with other international students.

To address this problem pragmatically, and thereby implicitly acknowledge the educational programmes' failure to make room for an education towards global competencies, KTH

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[6] Target 4.7 | By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development.
[7] KTH has had failed projects that worked towards integrated internationalisation. The most noteworthy one was the 'language track' launched by a handful of programmes in the early 2000s and later discontinued.

decided to establish a university-wide extracurricular 'Certificate of Global Competence' in 2016. The certificate consists of two elective courses and one study period abroad. The idea is that while students may not be given enough freedom in their programmes, they should still be given the opportunity to equip themselves with the knowledge, skills and attitudes necessary to function well in intercultural contexts, i.e., acquire global competence (Deardorff 2009).[8] At the same time, the certificate is a means to enhance the interpersonal contacts that are commonly referred to as 'internationalisation at home', as well as to encourage studies abroad.

By describing the process of developing and implementing the certificate, and relying on data from the first course offered, this paper proposes to evaluate the initiative with three questions: 1) was it a successful way of introducing educational change; 2) is the model sustainable or prone to failure, and most importantly, especially in the CDIO context, 3) is this type of extracurricular certificate programme effective to deliver the intended outcomes? We also argue, independently from these questions, for a more explicit account of global competencies in future versions of the CDIO framework.

THE CERTIFICATE OF GLOBAL COMPETENCE

Implementing a university-wide initiative to offer students the possibility to acquire global competency has been a noteworthy journey to those involved. Starting as a vague idea in 2013 and an online search for best practices around the globe in 2014, the details of the certificate were developed in 2015 by a small working group from KTH Language and Communication in tandem with a reference group comprising representatives from the university's central management (KTH's Vice Dean of Faculty, the head of the International Relations Office), faculty members, and two representatives from the Student Union.

Since this certificate was an unprecedented model for Swedish universities, the validation process was long and complex. To raise awareness within management and faculty, the idea was pitched in a number of occasions to various committees and networks within the university. The initiative was similarly discussed with colleagues from other universities during a nationwide conference on the development of engineering education (Kjellgren et al. 2015).

KTH's CGC was put forward as an effort to help engineering students attain global skills in a visible, measurable, simple and systematic way. This global competence could be beneficial whether the students intend to work in Sweden or abroad, and in a number of areas such as academia, trade and industry, or the public sector. The suggested advantages of promoting systematic work in the area at university level have been as follows.

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[8] An established list of global competencies could not be found on in the literature. Diversity, a buzzword in this context, characterises much of the theory building, together with much overlap and re-invention of the wheel, as pointed out by Spitzberg & Changnon (2009). In their typology of models for intercultural competence, the compositional model with its differentiations of knowledge, skills and attitudes is the one most naturally akin to European university courses and the model that inspired us when developing the certificate. As for the specific content, we acknowledge the limitation inherent to anything supposed to be taught in a university course, and the focus we have chosen is reflected in the intended learning outcomes of the two courses, listed in Tables 1 and 2.

Benefits for institutions

- attract students to more rewarding foreign studies and increase internationalisation activities;
- increase quality review and quality assurance for studies abroad;
- provide current education programmes with a complete model to be introduced without having to change their educational plans;
- strengthen the university's international profile and broaden recruitment of new groups of students;
- support and encourage successful meetings between domestic and international students.

Benefits for students

- utilise an attractive and flexible model that offers an official certificate;
- facilitate the students' studies of global skills;
- acquire global competence while at university;
- enhancing their employability
- strengthen their further developing of global competence after graduation.

The suggested model was designed to create a broader sense of community across cultures and school boundaries as well as promote better work with diversity and internationalisation. The certificate is undoubtedly in line with the university's vision (2027) that sees 'KTH as a custodian of the role of technology in society who takes responsibility for its impact: creating innovative solutions to global challenges'. The certificate may be achieved within the university's approved elective credits, and it will be issued together with the degree certificate. The CGC should act as evidence that a student is well-prepared for today's global professional life.

The CGC model

The KTH Certificate of Global Competence consists of three compulsory parts. The first one focuses on theory and knowledge. The second one is where theoretical knowledge is put to the test in 'field practice', and a third component concentrates on documentation and reflection.

The three consecutive parts of the CGC are:

- Intercultural Competence, 4.5 credits
- Exchange studies or equivalent
- Global Competence, 3 credits

The two courses are offered both in the autumn and spring semesters. Details of each course's content and intended learning outcomes are shown in the following Tables 1 and 2. Subsequently, Figures 1, 2, 3 display the CGC model as additions to programmes at KTH of different length.

Programme students can apply for CGC courses when selecting regular courses. Students may apply for exchange studies at the end of the autumn semester for the upcoming academic year. In order to be eligible for the Global Competence course, the first course and subsequent exchange studies must be completed. The certificate is then issued together with the degree certificate.

Global competence should be built with a long-term perspective and is best cultivated through a combination of theory and practice. In order to put the theory from the first course into practice, the study period abroad is an integral part of the certificate. A study period abroad is an opportunity to explore and create understanding under safe circumstances while forming skills that should be further developed through lifelong learning.

The certificate does not feature mandatory language training, but the importance of language skills is highlighted in the first course, and language studies are encouraged. For a rewarding exchange, students should possess language skills of at least a B level according to the Common European Reference Framework for Languages (CEFR).

In order to count towards the certificate, the exchange study period should be of 12 weeks or longer, Minor Field Studies (MFS), degree project or internship abroad should be of 8 weeks or longer. For international students at KTH, the time in Sweden is taken into account. For KTH students who are not planning to study abroad, or have already studied abroad but still want to improve their global competence, it is possible to only take the first course – Intercultural Competence. International exchange students are also welcome to take this course.

To evaluate the effect of the first course related to the quality of the study abroad period and the students' ability to gain global competence, we plan to use questionnaires both before and after student exchanges, comparing certificate students to non-certificate students.

Table 1. Description of the course LS1600 Intercultural competence

Intended Learning Outcomes	Course content
• Show an understanding, grounded in personal experience, of how personal and cultural variation and diversity influence understanding, emotions, decision-making, communication and teamwork. • Problematize your own and others´ descriptions of culture and identifications based on, for example, gender, nationality, ethnicity, class, age, language and profession. • Give personal examples of knowledge, skills and attitudes that support and develop intercultural competence. • Explain how intercultural competence relates to KTH´s core values, global citizenship, and sustainable development. • Use simple and efficient methods to observe, analyse and work constructively, creatively and ethically with personal and cultural variation. • Reflect on critical intercultural incidents in a constructive and solution-oriented way. • Systematically document, reflect on, and give accounts of intercultural experiences and learning. • Present a personal action plan, grounded in self-awareness, for your continued personal development towards increased intercultural competence.	• With concrete examples and problem-based inductive learning, the course introduces the theoretical models needed for efficient reflection on, and analysis of, intercultural situations, communication and teamwork. • The course provides opportunities to learn and practice, individually and in groups, various practical methods for working constructively, creatively and ethically with personal and cultural variation and diversity, as well as for handling critical intercultural situations. • The course contributes to an increased level of self-awareness and understanding of important issues such as identity, stereotypes, norms and behavioural patterns. • During the course, we will examine roles and expectations, relevant to the student's specific profession, that may exist in different countries, companies and workplaces, and discuss what consequences this may have in, e.g., multi-disciplinary and international projects. • We discuss how intercultural competence relates to KTH's core values, global citizenship, and sustainable development. • The course also covers emotional aspects of international teamwork, living and working abroad as well as returning to your country. • Documentation, reflection and accounting of intercultural experiences and learning are brought up as a step towards personal development and future employability.

Table 2. Description of the course LS2600 Global competence

Intended Learning Outcomes	Course content
• Show an understanding, grounded in theory and personal experience, of how personal and cultural variation and diversity influence understanding, emotions, decision-making, communication and teamwork. • On the basis of relevant theories and personal experience, problematize your own and others' descriptions of culture and identifications based on, for example, gender, nationality, ethnicity, class, age, language and profession. • Work in constructive, creative, ethical, and solution-oriented ways with critical intercultural incidents related to multi-disciplinary and intercultural teamwork and leadership • Critically reflect on how intercultural skills relate to KTH's core values, global citizenship, and sustainable development. • Present systematically documented descriptions of, and self-reflections on, personal intercultural experiences and learning relevant to your future professional life. ○	• The course builds on LS1600 Intercultural Competence, as well as the students' own experiences from the stay abroad, which together with LS1600 constitutes the entry requirements. • The course gives a deepened, theory- and experience-based understanding of how personal and cultural variation and diversity influence understanding, emotions, decision-making, communication and teamwork. • We explore strategies and methods to enhance intercultural understanding and interaction in order to appreciate and benefit from personal and cultural differences in a constructive, creative and ethical way. • The course puts emphasis on global citizenship, sustainable development, situational leadership in intercultural environments, professional roles and ethics, communicative leadership in intercultural or multidisciplinary teamwork, and employability.

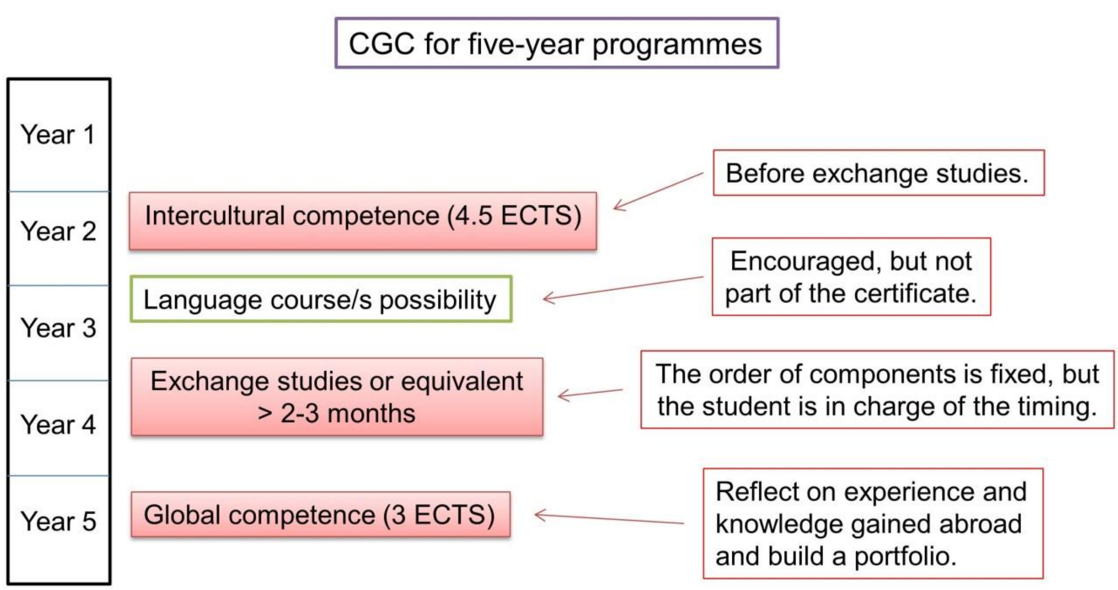

Figure 1. Certificate of Global Competence for a 5-year programme

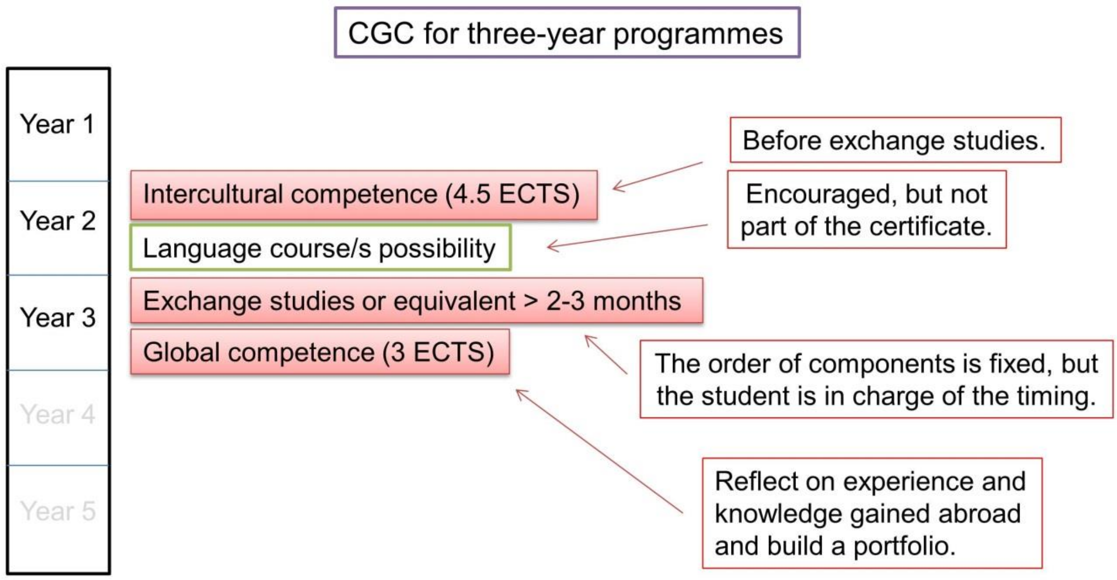

Figure 2. Certificate of Global Competence for a 3-year programme

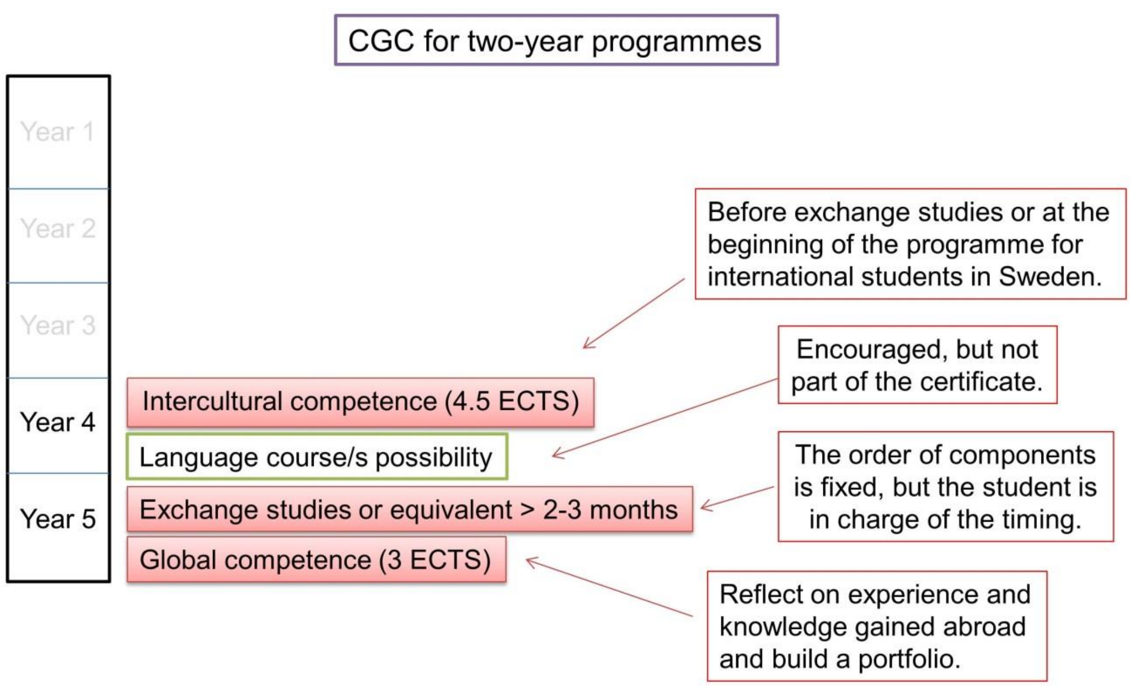

Figure 3. Certificate of Global Competence for a 2-year Master's programme

THE PILOT COURSE

The first course for the certificate, Intercultural Competence, was offered as a pilot in the autumn term 2017 over a period of 10 weeks to a limited number of students (established for 27, 32 admitted and 31 started the course). It was a blended course with a combination of interactive online lectures and workshops in the classroom (on four occasions). Assessments of individual and group assignments were done before, during and after the classroom meetings. Since increased self-awareness and expansion of comfort zones were two main themes, the students also worked continuously on self-reflection journals.[9]

The course offering has been evaluated by looking at three things: completion rate; course activity, and course evaluation. The course was designed to systematically work towards:

- an open and inclusive learning environment;
- coaching as opposed to formal educational tools to encourage student-centred learning and enhance motivation;
- hands-on tasks and learning by doing to allow new knowledge to be tested in real life already from the start;
- flexibility and the inclusion of students as course co-designers based on their continuous evaluation of the course;
- continuous feedback and support, from the teacher as well as from peers in smaller groups formed at the first meeting.

Completion rate of extracurricular courses, e.g. language courses, taken by KTH's programme students may vary. Personal motivation to take such courses often wins over the tendency to drop out of non-compulsory courses. For this course, of the 31 students who started, all but one finished, making for an exceptionally high completion rate of 0.97.

The course used continuous assessment to deliver both formative and summative feedback. It was designed to facilitate an even workload, and avoid end-of-course cramming, which is often seen in traditional courses with a big final examination. The use of a modern LMS facilitated the measuring of students' activity online, and even though the quality of activities cannot be deduced from numbers with precision, Figure 4 shows that activities were evenly distributed (the dip in late October corresponds to the mid-term break and the one in November-December with fewer scheduled online activities).

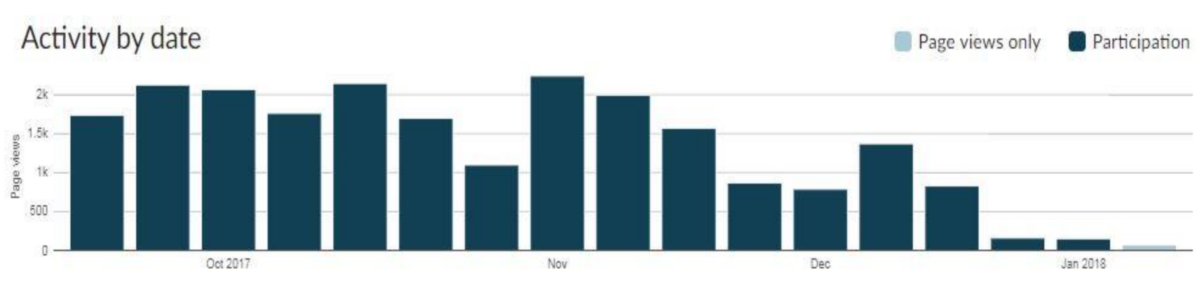

Figure 4. Online activity September 2017 to January 2018

[9] This section of the paper builds on the course analysis made by the course responsible, Björn Kjellgren, and the course teacher, Alena Ipanova.

KTH has used the Learning Experience Questionnaire (LEQ) for a few years as a main tool for course evaluation (see Berglund et al, 2015). The LEQ analyses students' experiences of courses on three levels, each measured with a number of statements for the students to agree or disagree with: the emotional level (meaningfulness, no 1-6), the cognitive level (comprehensibility, no 7-16), and the instrumental level (manageability, no 17-22). While primarily used as a tool for comparing different occurrences of the same course, and then as a means to develop courses, the following polar diagram (Figure 5) displays the picture of a very successful course. Unfortunately, the response rate, slightly less than 30%, makes it impractical to draw broad conclusions solely on the basis of the LEQ. The fact that the students were given ample opportunity to give feedback throughout the course could be a major reason why the response rate to this after-course evaluation was relatively low.

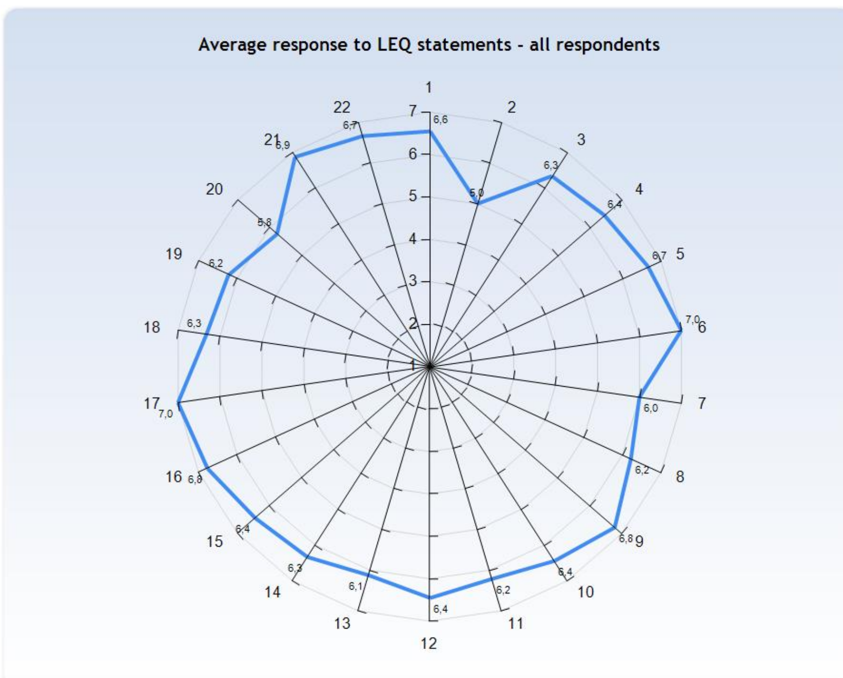

Figure 5. Average response to the 22 LEQ statements after the autumn 2017 course offering

DISCUSSION

We will now turn our attention to the questions posed earlier: has the initiative been a successful way of introducing educational change; is the model sustainable or prone to failure, and, most importantly, especially in the CDIO context, is this sort of extra-curricular certificate programme effective in delivering the intended outcomes?

The certificate was established partly as a response to the difficulty of introducing educational change in already established programmes. Even though the bureaucratic process proved to be a prolonged one, the establishment of the certificate was easier than it would have been if we were to revise 20 or so programmes by adding new courses. In an influential article, Hannan and Freeman (1984) postulated that it would be far easier to overcome the basic structural inertia of an organisational change and avoid failure, if the change did not disrupt what they described as the organisation's core features. Our initiative can be seen as an example of such change, since the university certificate has added something to the university's educational landscape without challenging the structure, content or mechanisms of the different programmes. The success of the implementation can, nevertheless, also be linked to the fact that we did not work at the organisational borders, but directly with the central management. This means the initiative has in fact not only been a bottom-up one, but also one which has been implemented both from the top (management) and from the side (the extracurricular certificate activities).

With regards to the sustainability of the change introduced, the initiative must be observed over a longer timespan to collect more evidence. It may be argued that this initiative is a vulnerable enterprise, due to the dependence on a limited number of motivated faculty members who have been involved in the process (cf. Edström 2017). This dependency on motivated faculty members in this case relates to the few people involved in the design of the certificate, and to how even fewer were involved in the process of designing the courses. Even so, this is not the whole truth. The certificate would most likely not have been developed if it had not been for KTH's special pedagogical developers' initiative 2014-16 (Berglund et al. 2015, 2016, 2017, Kjellgren et al. 2018). The certificate is, therefore, also a result of the university's dedicated endeavour towards educational development. The long process of obtaining the university management's approval, and the certificate diploma that will be issued to students upon graduation, have given this initiative an official support and institutionalisation rarely granted to similar bottom-up initiatives.

As for the question of whether the introduction of the certificate has started to deliver all the assured benefits, there are no answers at this early stage. However, looking at the benefits for the students, listed above, we have evidence collected from the first course to support the notion that we are moving towards our goals. Concerning the benefits for the university, the effects of an intervention such as this will need even more time. Yet it will likely not be feasible to assess the effect of this certificate programme isolated from other projects. Some of the benefits, for example, those linked to the quality assurance of studies abroad, should be assessed as part of the work with the certificate programme, but the causal relationship to other benefits will be much harder to establish. Given that internationalisation is one of three focus areas for KTH's current president, the measures to support internalisation already in place are likely to be complemented by new ones. In the end, it will be the totality of efforts that will matter, in combination with a host of factors external to the university.

The last question additionally addresses the CDIO context and whether we should be wary of this sort of extracurricular model. Is this not the sort of add-on that we should systematically strive to leave for well-integrated programme syllabi? Our reflection is that perhaps we need not be overly worried. In the course evaluation questionnaire referred to earlier, we asked how the students thought the content of the course could have been integrated or better synchronised with their programme, and received three different answers that we think are valuable starting points for discussions.

The first answer was simply 'make it a mandatory course in the programme syllabus', which could perhaps be taken as an intuitive answer. This was also an opinion we heard from some members of university management when we presented the idea to KTH's Directors of first and second cycle education. Others were, however, quick to point out that most options tend to become less motivating when made mandatory, arguing for the attractiveness of the certificate not being mandatory. Furthermore, as stated earlier, the very difficulty of modifying existing programmes with extra courses was one of the starting points of the whole certificate process.

The second answer we received was ‘It’s already an integrated part of my programme, and in a good way too.’ This was less expected, but of course makes sense from a participating student’s perspective. For a student, the content of the certificate is as real a part of the university education as anything else. The only prerequisite for the existing programmes to allow for this student-design idea would be to allow the students to modify the programme by taking these courses, and adding the study abroad period, which is something that most programmes already do, or are expected to do. Since the certificate does not put any stress or add administrative burdens to the programmes, while still enhancing them with this elective component, it is very appealing.

Having said that, we should not ignore the lack of connection between what the students can learn by working towards the certificate, and the content of other parts of their programmes – the parts that actually make up for the entire programmes in the eyes of the directors, teachers and councils. While waiting for a better integration, the third student answer seems quite reasonable: ‘Make the teachers take the course.’ If we strive towards what Spencer-Oatey (2015) calls the ‘truly internationalised university of the future’, it is not enough to have the involvement of university top management and the students. Comprehensive internationalisation must be a concern for management, administration, researchers, teachers, and students alike. While we presently welcome staff also to the student course (and we will have a few taking the first course this spring), we are looking at ways of strengthening education for global competencies, complementing other activities or opportunities already present, through the development of a new course in teaching and learning in higher education, aiming at teachers and researchers, as well as through workshops for other staff.

CONCLUSIONS AND FUTURE WORK

After running the first course in the three-step completion of KTH’s Certificate of Global Competence, the students’ course evaluations show positive results as described above. In the spirit of Scholarship of teaching and learning, we will continue to document and evaluate the certificate. As noted, the comprehensive integration of the certificate with undergraduate engineering programmes, in line with what the CDIO Initiative advocates, has not been addressed, but circumvented. The certificate has given the students a viable option to develop important competencies, empowered and encouraged them to further hone their skills, but the connections to regular programme activities have been left for them to make on their own. Raised awareness of global competence among the faculty would probably contribute positively to the long-term project of making comprehensive internationalisation a more salient part of the university culture, thereby also helping create a positive feedback loop inspiring even more students to engage with the certificate and with internationalisation.

Global competency plays a central role within the scope of internationalisation of higher education. The importance of globalisation as well as the knowledge, skills and attitudes related to it has been acknowledged in the current edition of the CDIO Syllabus, possibly to some extent in response to earlier appeals for an additional Standard that would explicitly address the dimension of internationalisation and mobility in modern engineering education (Campbell & Becker 2010). We believe this was undoubtedly a step in the right direction, but the attention this area deserves will still be difficult to achieve without something like a specific Standard, an ‘optional Standard’ of the kind proposed by Malmqvist, Edström and Hugo (2017), or internationalisation as a sort of mega-dimension in the CDIO framework.

The present situation, where much of what we call global competence *could* be taught in reference to a long list of different sub-items in the Standards, is in line with the integrated philosophy of the CDIO framework, but few teachers at an average technical university will see them as major intended learning outcomes for their own courses, and they could easily be construed as dispensable parts of an already crammed programme syllabus. Therefore, we regard the KTH solution of establishing an add-on certificate as a promising and relatively easy-to-implement solution in the short run. In the long run, we should strive to make teachers and programme directors keen and able to integrate these skills in true CDIO fashion. For this to happen, the third student suggestion mentioned earlier – to educate the educators and not only the students – would seem to be the most constructive option.

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BIOGRAPHICAL INFORMATION

Björn Kjellgren is an Associate Professor at the School of Industrial Engineering and Management (ITM) at KTH. He has a PhD in Sinology, has previously worked as a researcher in Social Anthropology, and has been involved in teaching and learning activities since 1994. Presently, he works as Director of Studies, and as Programme Director for two Bridging Programmes for Architects and Engineers with Foreign Qualifications.

Elizabeth Keller is a Lecturer at the Unit for Higher Education, Research and Development at KTH Royal Institute of Technology. She has had considerable experience working, living and travelling in different countries. Therefore, she is very interested in intercultural communication. She has been teaching since 1989, and her current academic interests include internationalisation of Higher Education, faculty development, recent student learning styles, and evolving technologies.

Yoko Takau-Drobin is a Lecturer of the Japanese language and culture at KTH Language and Communication, the School of Industrial Engineering and Management (ITM), KTH Royal Institute of Technology in Sweden. She is also a PhD candidate at the University of Gothenburg, and is writing her dissertation on Japanese historiography.

Corresponding author

Björn Kjellgren
Dept. of Learning in Engineering Sciences
ITM School
KTH Royal Institute of Technology
Teknikringen 14, 100 44 Stockholm
+46 (8) 790 61 25
bjoern@kth.se

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TEACHING COMPUTER PROGRAMMING USING GAMIFICATION

Siew Peng Shorn

School of Engineering, Nanyang Polytechnic, Singapore

ABSTRACT

There are many challenges in teaching computer programming: the diversity in students' ability and aptitude levels; the time-consuming nature of programming; and the difficulty in motivating students to learn computer programming. Gamification refers to the application of gaming elements to non-game context, such as education, with the goal of increasing the engagement of students and inspiring them to continue learning. This paper presents the methodology of incorporating gamification elements in the teaching of computer programming and investigates the effects of gamification on students' learning gains and interest in learning computer programming at the School of Engineering in Nanyang Polytechnic, Singapore. Key findings on the extent gamification supports students' learning gains and interest in learning computer programming will be shared. Finally, the challenges faced in planning and designing appropriate educational games to teach computer programming will also be highlighted.

KEYWORDS

Gamification, Learning Gains, Interest in Learning, Computer Programming, Higher education, Tertiary education, Standards: 8

Note – In the context of Nanyang Polytechnic, the term 'course' refers to a 'program' while the term 'module' refers to a 'course'. For example, *Diploma in Electronic Systems* is a course; *Computer Programming* is a module.

INTRODUCTION

Generation Z youth is technology-savvy. They have digital technology and internet technology readily available to them at very young age and they are exposed to games or gamified activities that are available on their mobile phones and computers. The Generation Z youth also engages and maintains various social media platforms such as Facebook, Twitter and Instagram. They like to have fun and prefer non-verbal communications using digital technology than verbal communications. However, they tend to have short attention spans. The very nature of the Generation Z youth posts challenges in motivating them to learn computer programming, which is often perceived as a boring, time-consuming and difficult module.

Gamification, the use of game design elements in non-game contexts (Deterding, Dixon, Khaled, & Nacke, 2011), might overcome the challenges faced in the teaching of computer programming. As gamification uses "game-based mechanics, aesthetics and game thinking to engage people, motivate action, promote learning, and solve problems" (Kapp, 2012), it provides an avenue for capturing the attention spans of people. The goal of gamification is to maximize enjoyment and engagement through capturing the interest of learners and inspiring them to continue learning (Hwang, Hong, Cheng, Peng, & Wu, 2013).

Active learning increases student performance in science, engineering and mathematics (Freeman, et al., 2014). Gamification, a form of active learning, is gaining ground in education. Some research showed that, if gamification was properly applied, it could improve attendance (Fotaris, Mastoras, Leinfellner, & Rosunally, 2016) and engagement (Leong, Koh, & Razeen, 2011) , enhance understanding and consequently enhance performance (Mekler, Brühlmann, Opwis, & Tuch, 2013) . A study using an online game layer in teaching introductory programming found that gamification could significantly improve student engagement (Leong et al., 2011). Another study found that a gamified learning approach using a combination of "Kahoot!", "Who wants to be a millionaire" game and "Codecademy" for computer programming class was motivating and enriching for both students and instructors (Fotaris et al., 2016).

Learning to program is difficult, especially for novice programmers (Piteira & Costa, 2013). Gamification may offer opportunities in solving these issues. Most studies focused on the engagement and motivation factors of gamification. This paper studied the effects of the gamified learning on students' situational interest and learning gains in computer programming in a pilot study at the tertiary engineering education.

METHODOLOGY

The study focuses on the effectiveness of using gamification in teaching computer programming module, a module offered in the first year of two engineering courses at Nanyang Polytechnic, Singapore. The module was taught using C programming language. Two groups of students with similar profile, the experimental group and the control group, were identified. Gamification was applied in lectures and tutorials for teaching the experimental group while only traditional methods were used in teaching the control group. At the end of the semester, a common test and a survey were conducted for both groups to examine students' academic performance and learning gains. For the experimental group, a survey on situational interest was also conducted to examine students' interest in computer programming after experiencing gamified learning approach. Results were analyzed using quantitative methods.

Participants

Two groups of first year engineering students who were registered for the Computer Programming modules were invited to participate in the study conducted in academic year 2017 semester 1. The experimental group was from the Aerospace/Electrical/Electronics Programme (AEEP) and the control group was from the Diploma in Electronic Systems (DES). The module was taught over a period of 15 weeks. There were 86 AEEP students and 105 DES students in total in academic year 2017. These two groups have comparable academic results in the previous academic year 2016 semester 1 as shown in Table 1.

Table 1. Academic Results in Academic Year 2016 (before Action Research)

Group	Number of students	Mean Score	Standard Deviation
AEEP	92	68.8	12.7
DES	145	69.1	13.2

Control Group Class Setup

The control class had a weekly 2-hour practical session in a computer laboratory and a weekly 2-hour lecture & tutorial session in a lecture room. At the end of the semester, the students were required to complete a mini-project over a 3-week period.

Experimental Group Class Setup

Similar to the control group, the experimental group also had a weekly 2-hour practical session in a computer laboratory and a weekly 2-hour lecture & tutorial session in a lecture room. At the end of the semester, the students were also required to complete a mini-project over a 3-week period.

For the experimental group, gamified activities were introduced during the 2-hour lecture & tutorial session. Both team-based competitive games and individual competitive activities were conducted for the experimental group. All the games are directly linked to the module learning outcomes and used to replace tutorial questions with the same learning outcomes.

A total of 5 team-based games were conducted on a fortnightly basis. Students were asked to group themselves in teams of 3 to 4 members per team. Throughout the entire semester, students remained in their own teams. In each game, teams were ranked according to their order of completing the game correctly. Immediate feedback was given to students for errors in completing the game so that students would learn from their mistakes or misconceptions.

The first team-based game is a matching game. Each team was given a mixture of 14 different pseudocodes and 14 different flowcharts. Among the given pseudocodes and flowcharts, there were some containing errors and some that do not match. Students were required to compete among themselves in teams to identify two pairs of matching pseudocodes and flowcharts.

In the second game, a box containing many C identifiers as shown in Figure 1. Students were required to pour out all the given identifiers and identify the correct C identifiers. There was no information given on the total number of correct C identifiers present in the box.

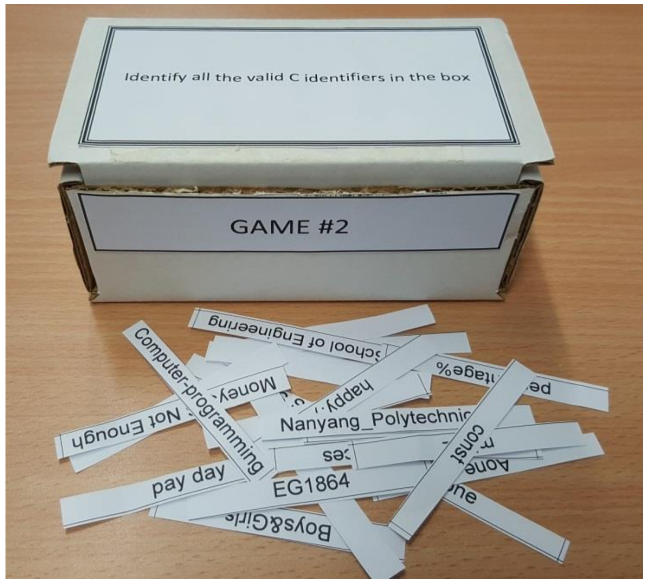

Figure 1. Competitive Game to identify the correct C identifiers

The third game focused on arithmetic and logical operations in C programming language through the use of magic square puzzle (see Figure 2). Each team in the experimental group was given a 3x3 magic square to solve. A 3x3 magic square was an arrangement of the numbers from 1 to 9 in an 3 by 3 matrix, with each number occurring exactly once, and such that the sum of the entries of any row, any column, or any main diagonal was the same. The magic square that was given to students contained some cells already initialized with numbers. Students needed to solve the magic square puzzle by filling up the remaining cells with integers 1 to 9 without repeating any of the numbers. They were required further to fill up each cell with the arithmetic or logical expression that evaluated a value equal to the number in each cell. While students enjoyed solving the magic square puzzle, they also applied the arithmetic and logical operations in C programming language.

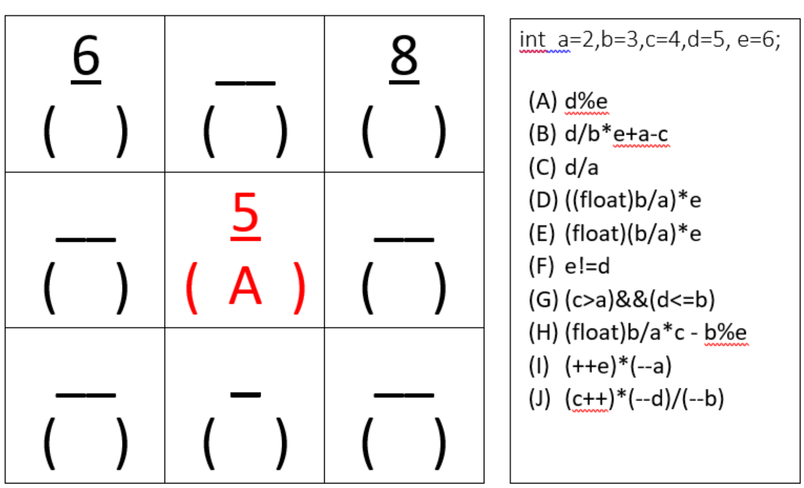

Figure 2. Magic Square Puzzle

In the fourth game, each team was given a short program written using arrays and a set of 20 resistors of different values. By understanding the program, each team had to identify the correct resistor from the given set. Students learnt about arrays and string functions through this game.

The fifth and last team-based game attempted to make a personal connection to students' enjoyable moments during the freshman orientation. During the orientation week before the start of the academic semester, students participated in a challenge that required them to construct a paper plane in teams. Students had a lot of fun and laughter during the orientation challenge. . In this last team-based game, teams were required to write program codes using loops to display a phrase such as "I enjoyed making and flying paper airplanes during orientation."

Besides the five team-based games, short individual quiz-like games were also conducted during the 2-hour lecture-tutorial sessions. In these short quizzes, students were required compete among themselves to identify the errors in a given program displayed onto the screen. There were multiple errors in each program. Each student was limited to one maximum correct attempt per session in order to give opportunities to more students. Figure 3 shows an example of an individual quiz-like game.

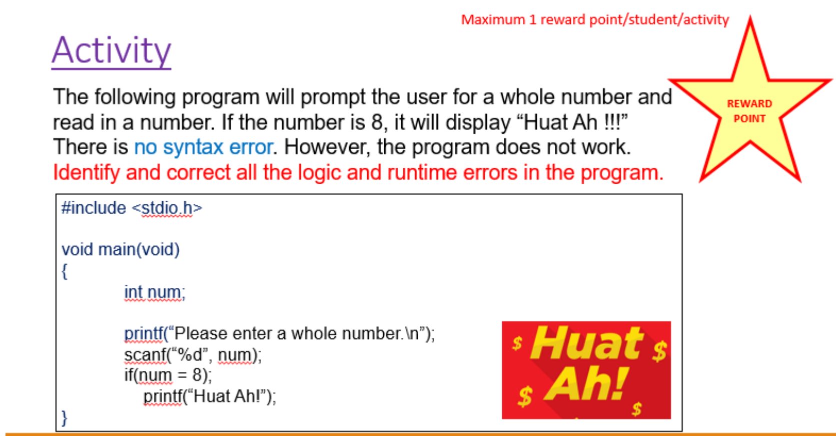

Figure 3. An example of an individual quiz-like game

An animation game from an online gamified programming learning website (www.codingame.com) to teach C programming loops was also used in the module. The animation game chosen was called "The Descent". A screenshot of the game is shown in Figure 4. In this animation game, a default non-working program was given. The animation story was about a spaceship called "Enterprise" that was going to land on the surface on a planet. There were 8 mountains of random heights on the surface. While the spaceship was landing, it must destroy the mountains in descending order of their heights, failing which the spaceship would crash into one of the mountains. Students learned about programming loops while playing the animation game.

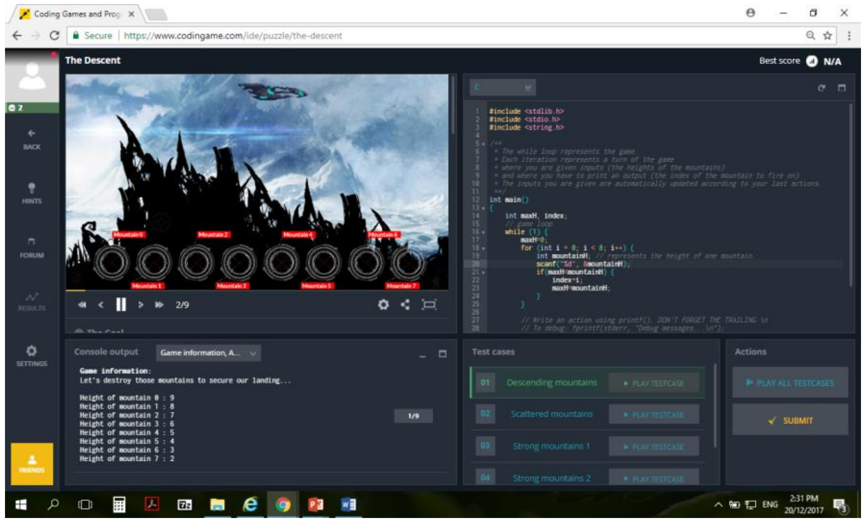

Figure 4. Screenshot of the animated Game "The Descent"

Points, Rewards & Leaderboard

Games have leaderboards and rewards (Glover, 2013). In this study, reward points and participation points were given. Reward points were given out for both team-based games and short individual games. For the team-based games, all the teams were ranked according to the order of completing each game correctly. Top three teams were awarded one reward point each in each game. In the individual games, one reward point was awarded to each correct answer, and each student was limited to one correct attempt per individual game. Participation points were also rewarded to students who participated in the team-based games.

A leaderboard was created and updated in Blackboard Learning Management System weekly. The purpose was to reflect the rankings of each student based on the reward points he/she had captured in class in these competitive activities. Their rankings were also displayed during the weekly lectures. The leaderboard with weekly rankings aimed to motivate students to move up in the leaderboard. Leaderboards served as a source of motivation for students because they saw their work publicly and instantly recognized, and because they could compare their progress with other classmates (Dominguez et al., 2013).

At the end of the semester, the total reward score for each student was computed. The maximum reward score for each student was capped at eight points. Top individuals with the highest reward score were awarded with individual prizes, and the best team with the highest reward score was awarded with team prizes. Both reward points and participation points were recorded and formed part of the overall score of the module.

CHALLENGES

In designing gamification elements into the module, one needs to take into consideration the diversity in the student population. Often, a class consists of academically strong and weak students, motivated and disinterested students, social and solitary students. To address this diversity, a mixture of individual games and team-based games were developed in this study. Total reward points were capped for each student. Reward points for individual games were also capped for each student for each individual game to provide opportunities to other students.

In forming the teams, students are allowed to form their own teams but there is a need to ensure each team has a good mix of academically strong and weak students. This allows the weaker students to learn from better students.

Different types of team-based games were created in this study and they were not repeated for different topics for novelty purposes. The process of having to create different types of games and thinking of the types of games that suit the topics is challenging and may take several days for each game. However, once the games were designed and created, re-using them is easy and does not require much time and effort. Unless automated, regular updates of reward points and leaderboard requires time and effort.

RESULTS AND DISCUSSION

A common test and a survey were conducted for both experimental and control groups at the end of the semester.

Students' Performance in Common Test

A common E-Quiz test was conducted for all the students in both the experimental and control groups at the end of the semester to evaluate the effectiveness of gamification in students' learning gains. The test consisted of 35 multiple-choice questions and covered all the topics in the module. It is used as a proxy for academic performance in this study. The results (normalized to a base of 100 marks) are shown in Table 2.

Table 2. Results of Common E-Quiz Test

	Sample Size	Mean Score	Median Score	Standard Deviation
Experimental Group	86	67	69	17
Control Group	105	54	54	17

Hypothesis testing is carried out to evaluate the effectiveness of gamification in enhancing students' academic performance measured using the common test results. Based on these data, it is concluded that it is statistically significant ($p < 0.01$) that an average student with gamified learning activities scored better than an average student without gamified learning activities. The quantitative results provide strong direct support for the hypothesis that gamification is effective in enhancing students' academic performance.

Cohen's d, the effect size of the mean score for measuring the magnitude of difference in mean between experimental group and control group is computed to be 1.06. Cohen provided rules of thumb for interpreting effect sizes, suggesting that |.1| represents a 'small' effect size, |.3| represents a 'medium' effect size and |.5| represents a 'large' effect size. Our results clearly indicate a large effect on the use of gamification in the improvement of mean score.

Post-survey

A common online post-survey on student assessment of learning gains was conducted for all the students in both the experimental and control groups at the end of the semester. The survey was voluntary. The survey items were adopted from Student Assessment of Learning Gains, a framework for measuring student learning gains and engagement (Lim, Hosack, & Vogt, 2012). In the survey, participants were asked about their understanding level on the concepts, applications, interest and confidence level. A 5 points likert-scale ranging from "Not at all", "Just a little", "Somewhat", "A lot" to "A great deal" was used. Among a total of 86 students in the experimental group, 50 students responded to the post-survey, representing a response rate of 58.1%. For the control group, 49 students out of a total of 105 students responded, with a response rate of 46.7%. Results of the post-survey are shown in Table 3.

The survey results showed that the experimental group has a slightly higher mean values than the control group across all the categories. It means that the experimental group students perceived themselves with higher understanding of concepts and greater gain in attitude, confidence and applications than students from the control group. However, these results are not statistically significant at significance level of 0.05 and of small effect sizes.

Table 3. Post-survey results

		Experimental Group	Control Group	Statistical Significance	Effect Size
Category	Number of items	Mean	Mean	p-value	Cohen's d
Concepts	8	3.26	3.15	0.26	0.13
Attitude Gain	3	3.20	3.03	0.17	0.19
Confidence Gain	6	3.15	2.99	0.18	0.18
Applications Gain	2	3.21	2.95	0.07	0.30
1-Not at all	*2-Just a little*	*3-Somewhat*	*4- A lot*	*5- A great deal*	

Survey on Interest in Computer Programming

Interest increases learning. Two types of interest have been identified by researchers, namely, individual interest and situational interest. Students tend to be more engaged if what they are learning is related to their individual interests. Situational interest is spontaneous, transitory, and environmentally activated (Krapp, Hidi & Renninger., 1992). Unlike individual interests that are developed over a long period of time, situational interest is temporary and triggered by external environment. Situational interest often precedes and facilitates the development of individual interest (Krapp et al., 1992). Moreover, situational interest is changeable and partially under the control of teachers.

According to the four-phase model of interest development (Hidi & Renninger, 2006), the first phase of interest development is a triggered situational interest. If sustained, this first phase evolves into the second phase, a maintained situational interest. The second phase may lead to the third phase characterized by an emerging individual interest and eventually the final phase, a well-developed individual interest.

A more detailed survey on situational interest in computer programming was conducted for the experimental group. A total of 53 students responded. The survey was conducted at the end of the last team-based game. In the survey, participants were asked questions on triggered situational interest, maintained situational interest feeling and maintained situational interest value based on a three-factor model developed by Linnenbrink-Garcia for academic domains (Linnenbrink-Garcia, et al., 2010). A 5 points likert-scale ranging from “Not at all”, “Just a little”, “Somewhat”, “A lot” to “A great deal” was used. Results of the survey are shown in Table 4.

Table 4. Results of Survey on Interest in Computer Programming

	Number of items	Mean
Triggered Situational Interest (SI)	4	3.06
Maintained Situational Interest (SI) Feeling	4	3.14
Maintained Situational Interest (SI) Value	3	3.30

Triggered-SI measures the level of grabbing students’ attention. Maintained-SI feeling measures whether the games are enjoyable and engaging. Maintained-SI value measures whether the games are viewed as important and valuable (Linnenbrink-Garcia, et al., 2010). The results showed that the gamification is able to achieve maintained situational interest beyond triggered situational interest. Maintained situational interest is important for developing individual interest.

CONCLUSION

This study explored the effect of gamification, an active learning method, in a computer programming module on students’ learning gains and interest in a tertiary institution. The findings suggest that gamified learning approach has positive effect on students’ academic performance and situational interest. Its effect on students’ assessment of learning gains is positive but of small effect size and lack of statistical significance when compared to traditional teaching approach.

This study is limited by several factors that are beyond the control of the author. First, the two groups of students under study may have different background such as previous education, experience and skills, motivation and interest. Secondly, the two groups were taught by different lecturers. Notwithstanding all the lecturers in this study are experienced in both programming and teaching, they have different personalities and different styles of teaching. This factor might be minimal as they were able to build good rapport with students and received very good feedback from the students. Finally, a single cycle is carried out in this study. More cycles of study would need to be conducted in future to verify the results.

Increasingly, educators have looked into gamification as a tool to improve students’ learning outcomes. What kind of game principles to adopt and how to contextualize the games to meet the learning outcomes might be a challenge. There is no one-size-fit-all solution. Considerable amount of time is needed for planning, games design and creation, gamification execution, and regular rewards and leaderboard updates for the first run. However, once the games and leaderboard system are developed, re-using them for subsequent runs is easy and requires little effort.

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BIOGRAPHICAL INFORMATION

Siew Peng Shorn, is the Programme Manager for Aerospace/Electrical/Electronics Programme and a Deputy Manager in the Embedded Technology Centre (Device Applications Section) at the School of Engineering, Nanyang Polytechnic. He is in charge of the overall management, curriculum review and development for the Aerospace/Electrical/Electronics Programme. He is also the Module Coordinator of Computer Programming module in the Aerospace/Electrical/Electronics Programme.

Corresponding author

Siew Peng Shorn
School of Engineering
Nanyang Polytechnic
180 Ang Mo Kio Avenue 8
Singapore 569830
65-6550-0585
siew_peng_shorn@nyp.edu.sg

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DEVELOPING STAFF FOR EFFECTIVE CDIO IMPLEMENTATION

Gareth Thomson

Mechanical Engineering & Design, Aston University, Birmingham, UK

Robin Clark

Warwick Manufacturing Group, University of Warwick, Coventry, UK

ABSTRACT

CDIO Standard 10 – Enhancement of Faculty Teaching Competence – is important if the implementation of CDIO is to be effective and if the student learning is to be fully realised. A clear and robust approach to the development of staff teaching competence is something that benefits the wider institution even if CDIO is not the primary framework for delivery.

This paper discusses the results of a survey administered within the UK and Ireland CDIO and related community that explores the training and development opportunities afforded staff when they are engaged with CDIO teaching practice. The survey suggests that there is little bespoke training taking place and that this is a gap that needs the attention of the community. It does emphasise the importance and value of the network in promoting some sharing, but a more evidence based approach to Standard 10 would be beneficial to all.

KEYWORDS

Staff development, competency, training, motivations,
Standards: 10

INTRODUCTION

CDIO Standard 10 – Enhancement of Faculty Teaching Competence – is important if the implementation of CDIO is to be effective and if the student learning is to be fully realised. A clear and robust approach to the development of staff teaching competence is something that benefits the wider institution even if CDIO is not the primary framework for delivery.

In the UK, the advent of the Teaching Excellence and Student Outcomes Framework (TEF) (Department for Education, 2017) has afforded the engineering education community an opportunity to make progress in the area of staff development. The TEF is an attempt to 'measure' teaching excellence and the value of the learning process in enabling students to get meaningful jobs on graduation. In engineering education, the CDIO framework is uniquely placed to promote teaching excellence within a real-world focused learning environment. To make this effective, staff need to feel confident and empowered in enabling learning using the CDIO framework.

To date, much of the staff development and training that takes place is generic and often not focused on engineering as a discipline, let alone the CDIO approach. Experience suggests that much of the development of staff takes place on the job and with colleagues acting as mentors.

The recently completed QAEMP Project conducted by 8 institutions across Europe suggested that there is certainly a need to explore more structured CDIO focused training and development to support faculty as they engage with their teaching (Schrey-Niemenmaa et al. 2018, Clark et. al. 2015, Bennedsen 2016). In this project particular STEM based subject groups within the institutions assessed their competence over a range of 28 diverse criteria, some or which mirrored the CDIO standards, while others examined issues such as employability, entrepreneurial activity and the engagement of students in programme review and development. The aim was then to match institutions with weaknesses in particular areas with those strong in these areas and vice versa. It was found however that the criteria relating to "Faculty Development (knowledge and teaching)" was almost universally poorly rated in terms of mastery by the participants but was of significant concern to all. (Clark et al. 2016)

A review of recently published papers on CDIO also shows that initiatives to support schools in developing their processes and infrastructure to address Standard 10 are not particularly extensive in the literature (see Figure 1). This may be because it is seen as a particularly difficult problem to tackle which is likely to require a degree of institutional culture change, something that may not be in the gift of those typically active in the CDIO community.

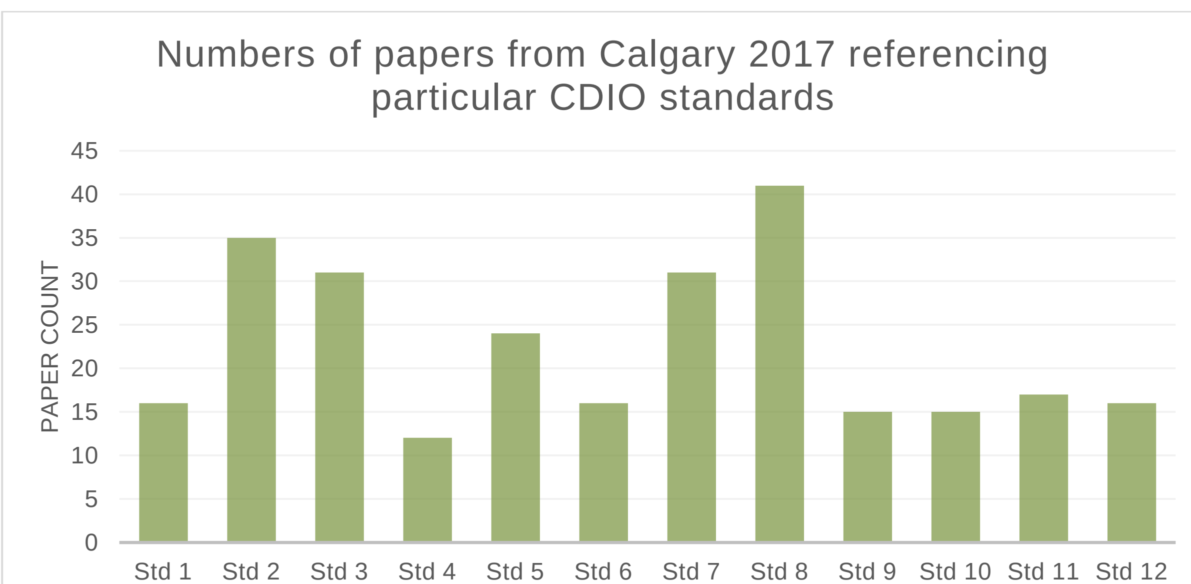

Figure 1. Papers at the CDIO Conference 2017 in Calgary, self-reporting as featuring particular CDIO standards.

Leong et. al. (2016) offered one of the few reports of a fully structured approach to staff teaching competence development. This paper reports experiences at Singapore Polytechnic where a number of processes are in place to both induct new staff and support and develop staff on an ongoing basis. This latter objective is achieved by a range of measures including formally trained academic mentors to support more inexperienced staff, platforms for sharing best practice, and developing a structure for staff development based around a number of competency domains.

Outside CDIO there are a few groups attempting to develop similar types of structures to support faculty in a relatively holistic way by drafting in academic mentors and specialists to support on an individual or programme basis (Yuen et. al. 2016) or to take a very top down approach to faculty development (Shankaranarayana et. al 2013) however neither approach appears to have been implemented as yet in a systematic or sustained way.

By contrast most of the work published in relation to Standard 10 tends to focus on discrete packets of staff development rather than a more structured overall approach with linked elements for staff at all levels in their career.

This is not unique to CDIO, with for example, Bhadani et al. (2017) and Cleveland-Innes et. al. (2017) describing formal training courses to help staff develop competences while other work has focussed on, spells in industry to support staff currency and focus (Kontio et. al. 2015).

A number of other papers reference Standards 9 and 10 though the focus of the paper is more on a mode of teaching or curriculum initiative with some degree of staff development implemented to allow for these. (eg. Wikberg-Nilsson et. al. 2017, Gommer et. al. 2016). In all cases however these tend to present localised elements of good practice rather than a strategic plan for whole faculty and career long development.

The issue of staff development, recognition and reward in the field of engineering education has been a topic of discussion for many years, Recent developments have seen the publication of a proposed framework by the Royal Academy of Engineering (2018). It is within this framework that potential new approaches to staff training and development could be located. Specifically within the UK, the value of the Higher Education Academy Professional Recognition Scheme in promoting development should not be underestimated, although specific guidance around active approaches to learning is not included (Higher Education Academy, 2018).

To help understand the issues around staff development and some of the drivers and barriers to developing holistic structures to support staff it was felt that an audit of current practice and views was required.

METHOD

To evaluate the views of the community, an online survey was developed and circulated among the UK & Ireland community of existing and potential CDIO members. This asked around 20 questions, formatted as multiple choice, factor ranking and free text questions and covered current practice with regard to staff learning and teaching development. The questions were developed and reviewed by both authors to ensure both coverage of the topic and clarity in the questioning. In addition to demographic data and a record of existing practices among the respondents, a gathering of views on what the participants felt were the key drivers and retarders in developing structures and resources to enable effective staff development was also recorded.

The survey collected the responses of 11 individuals from 11 different institutions.

RESULTS

Of the 11 participants in the survey, 6 were CDIO members while the remainder had expressed an interest in joining and had typically taken part in a CDIO conference or meeting.

An audit of the participants' position on the rubric rating for Standard 10 showed a full range of responses for both CDIO members and others (Figure 2) with no correlation between involvement or experience of CDIO and position on the rubric.

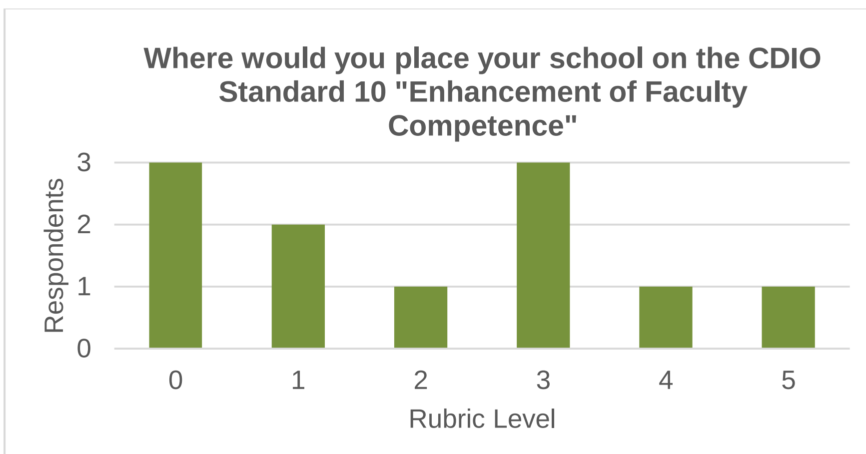

Figure 2. Self-assessment for Standard 10 among participants

This appears to highlight two issues. Firstly that even among very experienced CDIO members there was often very low ranking of compliance to this standard but also that the rubric itself is open to a significant degree of interpretation which was indicated by some of the responses given to justify the ranking. Eg. the participant evaluating their school at 5 – "Faculty competence in teaching, learning, and assessment methods is regularly evaluated and updated where appropriate" was largely justified due to the use of student feedback forms and normal module review. Other institutions using similar processes however felt this was not necessarily valid without a structured rather than ad hoc training framework.

The participants were also asked to rate what proportion of staff were involved in active learning and, in most cases, less than 40% of staff were involved. By implication, this suggested that a significant proportion of staff even within CDIO focussed groups continue to teach entirely using more traditional approaches. (Figure 3.)

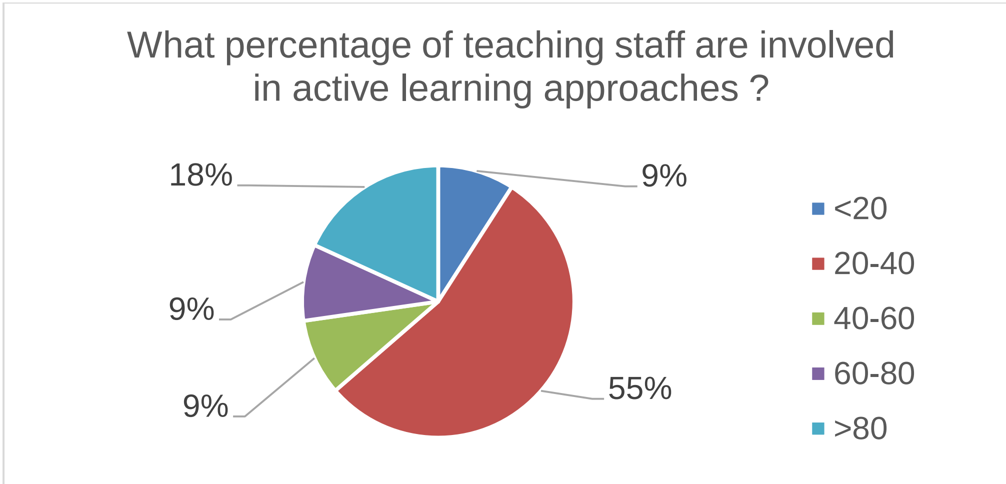

Figure 3. Proportion of staff in participant organisations involved in active learning.

Participants were also asked about the barriers preventing staff developing their teaching and learning competencies by ranking a range of options. (Figure 4)

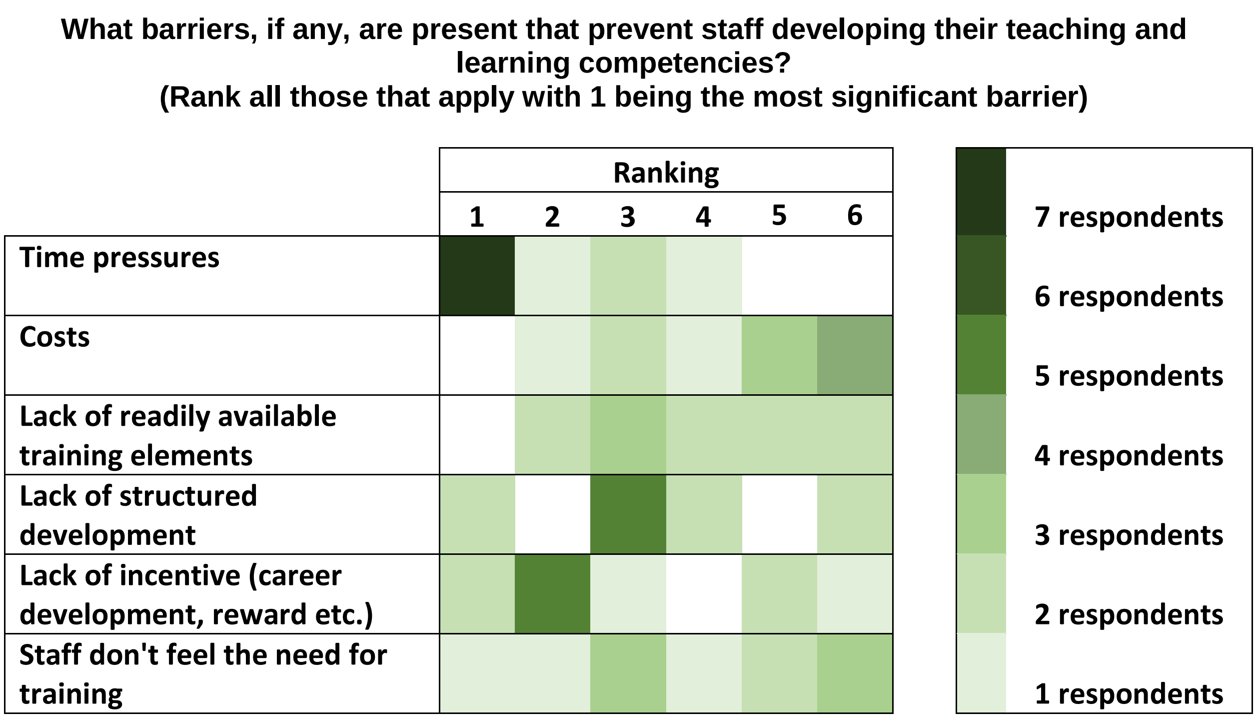

Figure 4. Barriers to developing teaching and learning competencies

It can clearly be seen from this, that time pressure is perceived to be a key barrier to staff developing their teaching competence. This also appears linked to the other relatively prominent barriers – that of lack of incentive and lack of a formal structure to develop the learning and teaching aspects of careers. Staff felt that while they would like to develop their competences, with no clear pathways to advancing their careers through learning and teaching, research and industrial involvement would become more pressing and rewarding.

The lack of structure in developing staff competences in learning and teaching was also apparent in some other responses from the survey. While within the UK Higher Education sector no teaching qualifications were traditionally required for academic posts, this is now becoming rare and new academics will normally be expected to obtain a postgraduate certificate in higher education within a few years of appointment. Beyond this however, and for those further into their careers, the training and support reported seemed very mixed and ad hoc. Participants reported in general that an individual's competence in teaching would be formally reviewed at their annual review but that structures and facilities to support staff grow their competence were piecemeal and ad hoc. This lack of structure means that the development of staff becomes a very 'personal' experience and one that does not actively promote consistency within the teaching team.

When asked about the mechanism for staff taking part in a development activity only two of the 11 respondents indicated that this would be "Part of a structured programme of development" with the remainder indicating that any development would be "ad hoc based on an immediate need or availability of training" or simply "self-directed". In the words of one respondent :

"Faculty teaching competence has been left to individuals or the Head of School to "manage" with no systematic approach to improvement or monitoring"

It was also apparent that development of competence over the wider faculty was often down to the motivation of individuals with little or no systematic drive to improve quality among all staff unless there were serious problems.

"It is ad hoc at our University - if people want to enhance their teaching, they attend the courses etc, but there has been no benchmarking study and no plan to do one"

"Enhanced peer support programme works well to lift the poorest teachers / modules - not necessarily in ALL though. Not enough is done to target the acceptable but not great (teachers)"

"Our Centre for Educational development provides opportunities for staff to develop in this regard, but it is at the discretion of staff to engage with them. There are individuals in our School who also implement good practice in this regard, but there is little dissemination or development practised"

"While a postgraduate certificate is a requirement for probation, this is a University scheme. The Faculty has no specific training and any that is in place is self sought and organised"

As in the last comment it was also noted that any structured training was often organised centrally and would not necessarily be tailored to the constraints and opportunities afforded by engineering disciplines, particularly with regard to active learning. Increasingly this gap is being considered one that needs addressing both from the staff and importantly the student experience viewpoints.

"We have a central teaching and learning department that runs training across the University. This is not always suitable for engineering types"

The respondents also reported that perhaps only 10% of staff in a given year would take part in a formal training event related to active and project based learning.

Given some of these issues and the lack of wholescale engagement in development of individual and collective teaching competence, the participants were asked to rank incentives which might be in place to help encourage and support staff to engage in learning development.
(Figure 5)

This however did not give a particularly good consensus with regards what might be the routes forward to encourage staff to engage in development activities. Note however the question referred to practices currently in place at the participants' institutions rather than a wish or ideas list which perhaps should feature in any follow-up study.

What incentives, if any, are present which help staff to develop their teaching and learning competencies?
(Rank all those that apply with 1 being the most significant incentive)

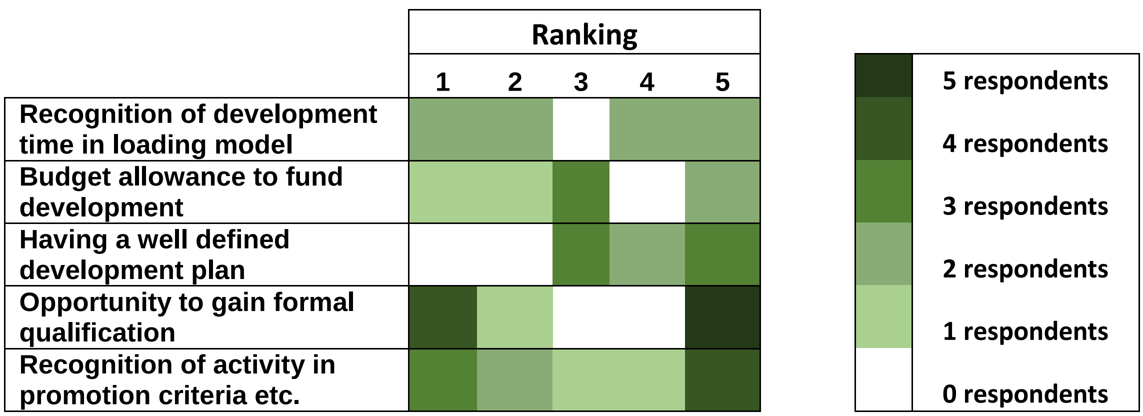

Fig 5: Incentives to support staff development.

The respondents were also asked about specific competencies which they felt were most in need of development which did highlight some key concerns of staff working directly with students on a day to day basis. Asked to list three, among the responses were:

"First is a recognition of the importance of a systematic review and appraisal of teaching competence.
Second is the ability to effectively use active learning practices within large classes.
Third is the ability to effectively reflect on learning within classes, and not have to wait for the summative assessment"

"1. Ability to supervise Capstones - coaching students in group DBT;
2 Ability to nurture the development of professional skills in all modes of teaching;
3. Ability to replace 24 hrs of chalk and talk with integrated learning experiences that target skills as well as knowledge acquisition"

The respondents were very much split down the middle with regards to whether they felt staff development would be an increased priority in future – (6 said "no", 5 said "yes").

Asked about the drivers and retarders of any change, a number of key themes could be seen from the respondents' comments.

It was recognised that the higher education arena is now very much a marketplace and good teaching and learning environments with strong student satisfaction should be to the fore with almost all respondents noting this as a key driver of change.

"Staff will have to develop or programmes will close"

"Student satisfaction is now very important to us"

Though others warned of caution regarding the over emphasis on student satisfaction as a measure of educational quality and that it could also act as a retarder.

"Reliance on student feedback and obsession with students "enjoying" their course are making schools risk averse and are significantly retarding innovation"

The use of external metrics – the UK's TEF and NSS – were highlighted by one respondent as being designed to foster change, but that the metrics used may not reflect good quality teaching and learning.

"The NSS does not accurately measure the teaching standards. The introduction of the subject level TEF may have a more granular impact, but it is still a blunt tool. So whilst the NSS and TEF may drive changes in the sector, they are unlikely to be effective at creating positive change when there are inadequate measures to record the improvements being made"

The key retarder was commonly seen to be senior management expectations regarding the development of high level research and industry portfolios, with teaching and learning arguably taken for granted.

"The continued emphasis on disciplinary research and implication that this is what defines and rates academic staff will always retard change or focus on teaching."

"Also, the appointment of professors who only do research in the hope that it will bring the University higher in world rankings - this means more teaching for other academics."

"Management are retarders of change, it's not seen as important."

CONCLUSIONS

This survey has shown that there is significant appetite among those directly involved in CDIO on the ground to develop learning and teaching competences on a personal basis and among colleagues. Barriers do exist however and there is unquestionably a degree of frustration that the rewards which could be reaped by a strong and proactive focus on the development of learning and teaching are not always seen by senior management.

In the UK, the introduction of the TEF has been designed to try to bring the student experience and quality of teaching and learning much more to the fore. This however is viewed with some caution as to whether this will achieve the desired goals or simply be "gamed" or divert attention away from core competencies. A recent survey of the UK Student Population () suggests that the TEF is liked and will remain, although it is inevitable that the metrics will further evolve over time. This is being explored at present, with work looking at what learning gain is and pilots taking place to explore the measurement basis at the subject rather than the institutional level.

While not a direct metric in the TEF, the increasing movement of most Universities within the region to expect some form of formal teaching qualification or recognition for all staff should be welcomed though a much wider and more mature model of continuous development and opportunity will be necessary for the sustainability of provision in a competitive climate.

CDIO Standard 10 however is an incredibly important one for the long term continuation of the initiative within institutions and more generally. The reliance on senior management to enable the culture change needed and recognise the need for continuous staff development can perhaps explain, at least from a regional context, why little deep and holistic work has been reported on staff development.

While very much a mixed picture there is some hope that the student voice and market forces will see increasing emphasis on learning and teaching and that as a collective CDIO and similar organisation can continue to drive forward learning and teaching competence. Within the region and the wider community there is an extremely positive and passionate group of academics keen to foster better approaches to learning and teaching and a very considerable enthusiasm to help develop strong approaches to helping staff develop their learning and teaching practices. As such, it is anticipated that this work will continue, both in terms of understanding and developing usable outputs for colleagues.

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BIOGRAPHICAL INFORMATION

Gareth Thomson is a Reader at Aston University, UK. He lead the implementation of CDIO at Aston, was a former Departmental Head and is involved in a range of pedagogical initiatives. He is a National Teaching Fellow, Principal Fellow of the Higher Education Academy and a member of the Institution of Mechanical Engineers Academic Assessment Committee.

Robin Clark is the Professor of Practice at WMG, University of Warwick, UK. He is a National Teaching Fellow, Principal Fellow of the Higher Education Academy and a member of the Board of Directors of the European Engineering Education Society (SEFI). He Chairs the UK and Ireland Engineering Education Research Network.

Corresponding author

Dr. Gareth Thomson
Aston University
Birmingham
UK, B4 7ET
g.a.thomson@aston.ac.uk

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FLIPPED CLASSROOM IN THE UCSC SCHOOL OF ENGINEERING: ENHANCING IN-CLASS TIME

Claudia Martínez-Araneda (cmartinez@ucsc.cl), Marcia Muñoz (mmuñoz@ucsc.cl)
Computer Science Department, Universidad Católica de la Santísima Concepción, Chile.

Matilde Basso (matildebasso@ucsc.cl), Claudio Oyarzo (coyarzov@ucsc.cl)
Civil Engineering Department, Universidad Católica de la Santísima Concepción, Chile.

ABSTRACT

In this work we present a peer-based Flipped Classroom model used by our UCSC School of Engineering Flipped Classroom teaching community. This model considers three essential components: technological resources for outside class learning, collaborative actitivites for in-class work, and a virtual learning environment to enrich the formative actions and strengthen asynchronous communications among the educational agents. We present application of this model to the Strength of Materials course of the Civil Engineering program and to the Programming Laboratory I of the Computer Science program. Our results show improvements in student performance and in teacher performance evaluations, where the use of emerging methodologies is positively valued. These results feed a virtuous cycle, as they turn out to be a motivating force for more faculty members to improve their practices and to incorporate active learning methodologies.

KEYWORDS

Active learning, flipped classroom, pedagogical competences, Standards: 5, 6, 7, 8, 10, 11.

INTRODUCTION

From 2008 to 2010, the School of Engineering of the Universidad Católica de la Santísima Concepción (UCSC) underwent a comprehensive curricular reform of its five undergraduate engineering programs, driven by the results of diagnostic studies that showed, among other problems: inflexible curricula having too many courses emphasizing technical knowledge acquisition rather than personal and interpersonal skills development, and lack of student motivation in their field of study (Loyer et al., 2011). This curricular reform was based on the CDIO initiative, which defines a framework for engineering education that emphasizes engineering fundamentals by conceiving, designing, implementing and operating real-world products, processes and systems. Its main resources are the CDIO Syllabus and the CDIO Standards (Crawley et al., 2014). As a result of this curricular reform, all undergraduate engineering programs at UCSC incorporated a student-centered teaching and learning approach, supported by the UCSC teaching and learning centre. This centre provides faculty training to aid the development of teaching skills (CDIO standard 10) and to boost innovations in their teaching and learning processes. It offers a teaching skills program which promotes both the implementation of active learning (CDIO Standard 8) and collaboration among instructors to improve teaching competences. Participation in teaching communities has been an effective mechanism for supporting instructors while conceiving, designing, implementing and assessing pedagogical innovations. The Flipped Classroom teaching community was created in 2016 and includes members of the Computer Science and Civil Engineering departments. Its peer-based model, described in greater detail later, provides instructors with a peer framework to support the use of active learning and information technologies in the classroom focusing on problem solving and collaborative work.

In this article we describe two teaching innovations that use the flipped classroom approach, implemented in the Strength of Materials course of the Civil Engineering program and the Programming Lab I of the Computer Science program. We present results about personal and interpersonal skills and academic performance, as well as future challenges for the Flipped Classroom teaching community. This work was funded in part by UCSC institutional grants for enhancing teaching and learning processes FAD[10] 11/2016 and FAD 06/2017.

FRAMEWORK

Recent works define Flipped Classroom as a teaching and learning model which dedicates the time spent in the classroom to practical and cooperative activities that facilitate the acquisition, practice and application of the theoretical knowledge, and transfers individual study to autonomous activities outside the classroom (Karabulut-Ilgu et al. 2017; Lee, Lim & Kim, 2017; Observatorio de Innovación Educativa, 2014; Tourón & Santiago, 2015). In this model, students take active learning roles and instructors guide and facilitate the learning process. This allows students to understand, analyze and apply information, and fosters their cognitive skills development (Ávila & Torres, 2014; Kong, 2015).

From a methodology implementation perspective, Hamdan et al. (2013) have identified a continuous learning assessment process which emphasizes permanent and on-time feedback to students. This requires the creation of flexible learning environments that go beyond the traditional physical and time boundaries of a class (Burbules, 2012). To this purpose, Tucker (2012) recommends using video for student learning outside class and emphasizes the importance of integrating the contents seen in the videos with the activities to be developed in class, so that they can effectively deepen and apply those contents.

The Flipped Classroom methodology is applicable to different educational contexts, showing improvements in the classroom environment and in learning outcome achievement levels, as well as increased student motivation and involvement in their learning process. Also, both instructors and students value positively the efficient use of in-class time and the fostering of autonomous activities that leverage information and communication technologies (Ávila & Torres, 2014; Chen et al., 2014; Observatorio de Innovación Educativa, 2014; Şengel, 2016).

Flipped Classroom Model

The peer-based flipped classroom model used by our Flipped Classroom teaching community considers three essential components of the Flipped Classroom methodology: the use of technological resources such as videos for outside class learning, collaborative activities for in-class work, and a virtual learning environment to enrich the formative actions and

[10] FAD: Fondo de apoyo a la docencia.

strengthen asynchronous communications among the educational agents. Figure 1 illustrates this flipped classroom model, which is based on Basso et al. (2017). It shows the five relevant actors: the instructor, the student, the media support group in charge of class video development, the pedagogical support group, formed by members of the teaching community, and an online teaching assistant in charge of answering student questions and monitoring their outside-the-classroom activities. It should be noted that the pedagogical support group is fundamental when helping an instructor unfamiliar with the Flipped Classroom methodology, and has only a sporadic advisory role with more experienced instructors.

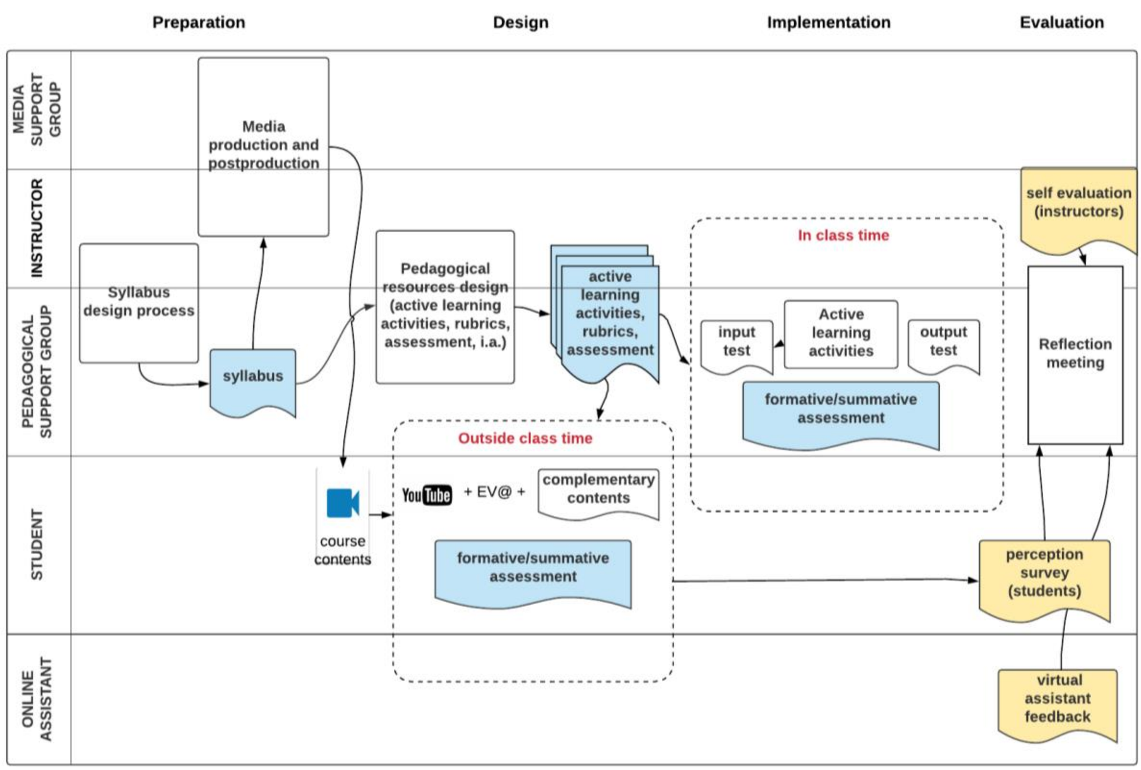

Figure 1. Flipped classroom model applied in Strength of materials course

Figure 1 shows each actor's participation in the model's four phases: preparation, design, implementation and evaluation. The square boxes indicate the model's processes, while the document icons show the artifacts associated to them. It also shows student activities outside the classroom and inside the classroom, organized in didactic sequences. Following Tobón et al. (2010), we define a didactic sequence as an articulated set of learning and assessment activities which, under instructor guidance, must be followed to achieve an educational goal.

The Preparation phase includes syllabus development and course media production and postproduction. The Design phase involves the development of the different pedagogical resources such as active learning activities and rubrics. The Implementation phase of the model is where students work in teams to solve problems during class time applying the disciplinary knowledge acquired outside the class (CDIO Standard 7). The Evaluation phase includes reflection meetings where instructors and the pedagogical support group discuss the results of student activities and the feedback gathered from all relevant actors for continuous improvement of the teaching and learning process (CDIO Standard 11). An important point is students continually receive feedback from formative and summative assessment from the instructor and the online assistant whether they are performing outside or in-class activities of the weekly didactic sequence.

In the following sections, we present the didactic sequences used in the Strength of Materials course and in Programming Lab I to promote active learning.

CASE 1. STRENGTH OF MATERIALS COURSE

In this case, we consider the Strength of Materials course taught during the 4-week summer term from December 18th, 2017 to January 12th, 2018 to 16 third-year Civil Engineering students. Two professors with experience in the field were in charge of the course, supported by three members of the Flipped Classroom teaching community with experience in active learning. The course was taught Monday through Friday in 4-hour modules, and it demanded the students' total dedication. The course syllabus describes student activities designed for individual learning outside the classroom, as well as those designed for in-class work. These activities' weekly structure is replicated week by week in order to facilitate the implementation of the didactic sequence, which is shown in Figure 2.

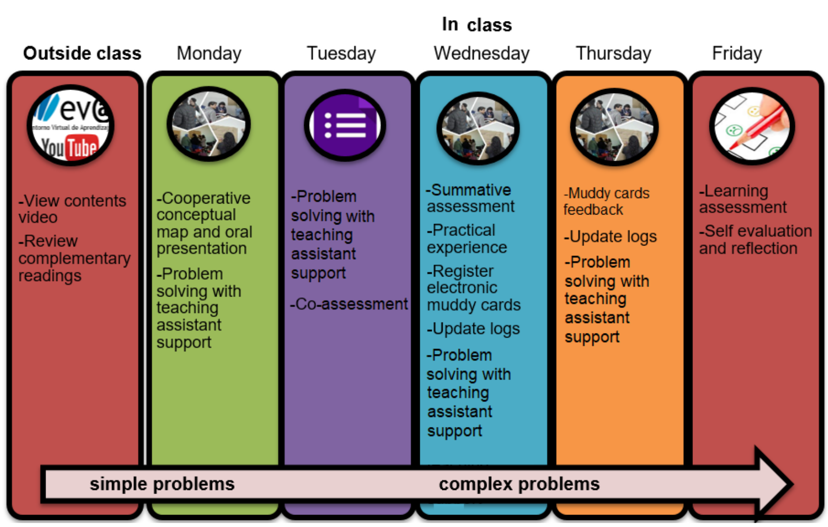

Figure 2. Didactic sequence for outside and in-class Strength of Materials course work.

This structure follows a progression in the learning activities complexity level. In other words, it starts with the use of superficial thinking skills (Bloom Taxonomy) such as the recognition and explanation of main concepts through concept maps, progressing to higher cognitive levels, by the resolution of simple and increasingly complex problems, and the analysis and application of practical experiences with concrete material. During the in-class sessions, students carry out different learning activities using active methodologies in teams mediated by the instructor (López, 2013; De Miguel, 2005). Diverse strategies such as: drawing concept maps, oral presentations, solving problems of different complexity levels, individual logs and practical experiences are applied so as to achieve meaningful learning (Osses & Jaramillo, 2008; Perdomo, 2016).

To strengthen the learning process, several pedagogical resources such as videos, readings, proposed and resolved exercise guides designed for individual outside class work are set out in an institutional moodle-based virtual learning environment. It also includes an asynchronous forum for student queries and a space for students to give evidence of the achieved learning outcomes, based on each week's practical activity with concrete material.

From an evaluation standpoint, the students' learning process is continuously monitored through quizzes, practical activitiy reports and exams. The in-class work methodology promotes immediate teacher-student and student-student feedback and continuous reflection by all actors. This reflection is carried out systematically during implementation by using various techniques, such as muddy cards, leading questions, peer feedback in problem solving, among others. A student survey is applied in the evaluation stage to collect information about their preferences and perceptions regarding the type of activities carried out outside and inside the classroom (McNally et al., 2017).

Results

Figure 3 shows the results of this student survey regarding students' preferences. Most students lean towards classes using a b-learning (blended learning) approach (56%), priviledging practical over theoretical work (62%) and in which they can actively participate and learn in collaboration with others (94%). A significant majority of students (81%) recognize the importance of having resources such as readings, videos or other complementary material in the learning process.

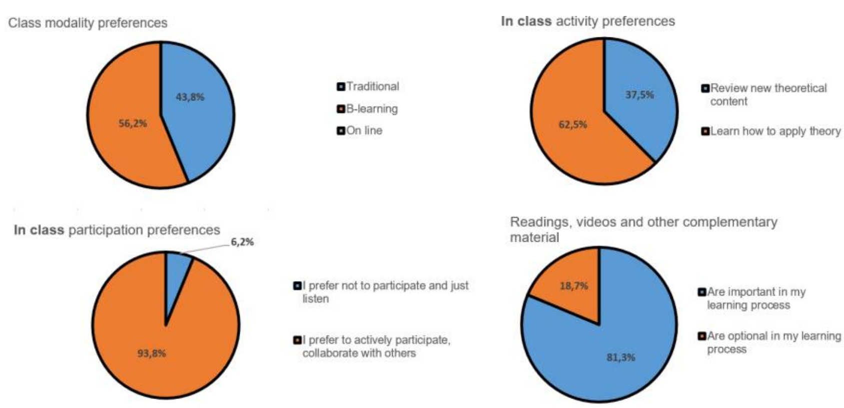

Figure 3. Students' preferences regarding the type of outside and in-class work

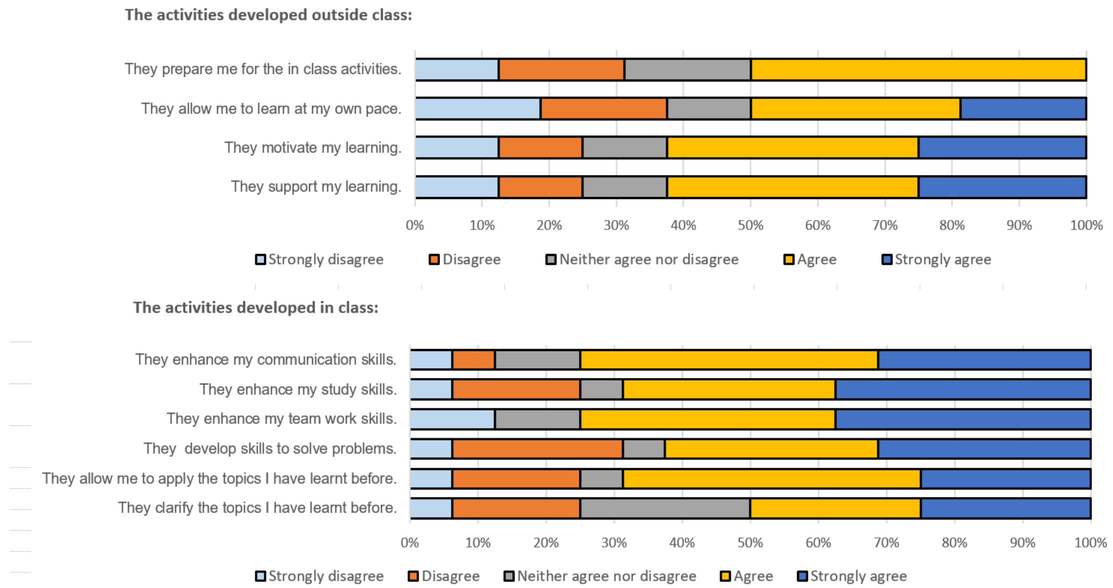

Figure 4. Students' perceptions regarding outside and in-class activities

Figure 4 shows the results of this student survey regarding students' perceptions. More than 50% of students agree that the activities developed outside class time motivate and support their learning process. Students positively recognize that the in-class activities improve their communication skills and teamwork (75%). They also recognize that this methodology allows them to put into practice what they have learned and boosts their study skills (69%).

CASE 2. PROGRAMMING LAB I

In this case, we consider the two spring term versions of the Programming Lab I course taught to first-year Computer Science students from August to December of 2016 and 2017. A professor with experience in the field and in active learning methodologies was in charge of the course. The course demanded 5 hours per week of in-class time during 16 weeks. These two versions of the Programming Lab I use ADPT++, an active learning method described by Martínez & Muñoz (2017) which adds flipped classroom strategies to the original ADPT (Analysis - Design - Programming – Testing) method described by Martínez and Muñoz (2014) (CDIO Standard 5). Figure 5 shows the didactic sequence for this lab, where stage 0 corresponds to outside class activities, where students must watch videocasts allocated in a Youtube channel covering the theoretical fundamentals to be applied in classes, as well as review complementary readings. Stages 1 to 3 are related to in-class activities. In stage 1, in-class work begins with a formative test developed by means of a Google Forms tools to detect whether students have previously seen the videos and to make sure they are ready for other in-class activities. In stage 2, students follow the ADPT sequence, which consists of solving a problem in teams and generating the deliverables for the ADPT stages. This activity is assessed using two specially designed rubrics: (i) a ADPT process-product rubric, oriented toward assessing learning outcomes associated to solving problems applying disciplinary knowledge, and (ii) a rubric designed to assess issues related to teamwork. Finally, in stage 3 the instructor gives students feedback reinforcing theoretical aspects with a close reflection activity guided by conceptual questions.

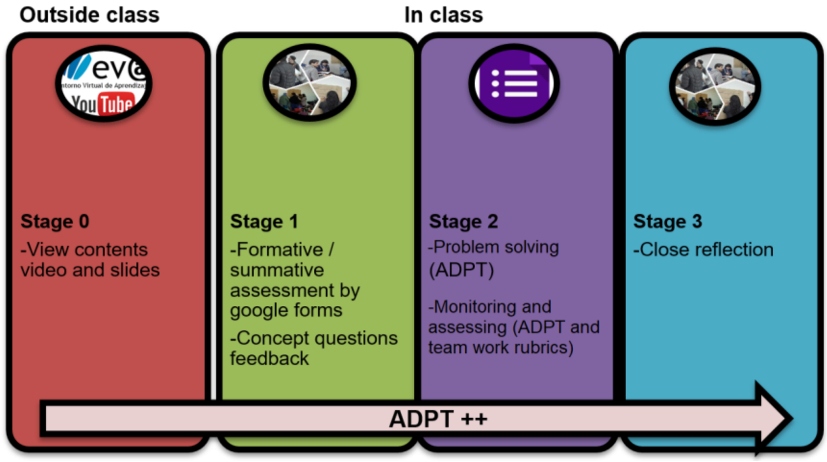

Figure 5. Didactic sequence outside and inside class Programming Lab I work

Results

In this lab, students follow 3 didactic sequences per semester and their grades are calculated assigning weights of 80% to process-product performance and of 20% to teamwork performance. Figures 6, 7, and 8 show grade results for the Programming Lab I course in terms of the student performance in Problem 1, Problem 2 and Problem 3, respectively. We must note that the ADPT active learning strategy was first applied in 2013, while the ADPT++ strategy was followed in 2016 and 2017. Results show an improvement in student performance starting in 2013, seen as a of the score boxes toward higher scores.

Figure 6 shows that grade dispersion for Problem 1 is high regardless of the methodology used. In the case of year 2017, the large grade dispersion for ADPT++ can be explained by noting that 20% of students did not watch the video before class (Source: Google Analytics). However, by the time students follow the second didactic sequence in Problem 2, grade averages are higher and grade dispersion is much lower for both the ADPT and ADPT++ active learning methods. When students follow the third didactic sequence for Problem 3, which is more challenging, our preliminary results show that the use of Flipped Classroom in ADPT++ results in much better average scores and lower grade dispersion.

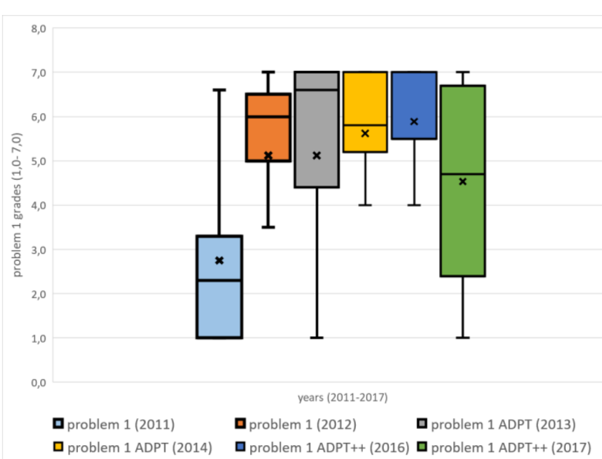

Figure 6. Problem 1 grades, 2011 to 2017

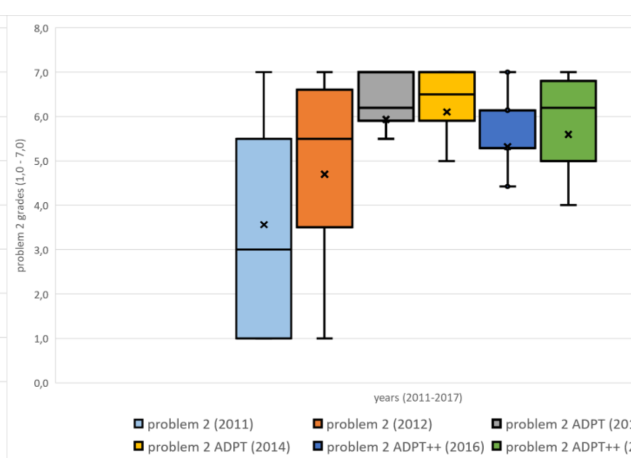

Figure 7. Problem 2 grades, 2011 to 2017

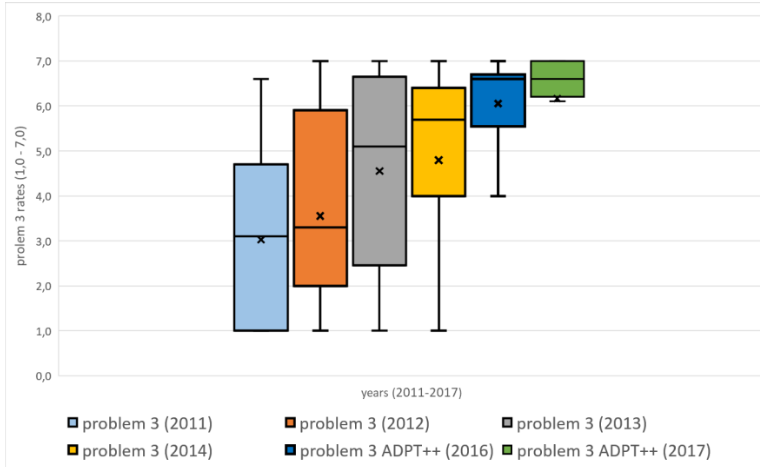

Figure 8. Problem 3 grades, years 2011 to 2017.

Figure 9 shows results from the teacher performance survey given every six months to students in all courses, which allows evaluating different aspects of teaching. In this case, only those items related to activities that facilitate self-learning, promotion of autonomous and collaborative work, and incentive to reflection on learning are shown. In all of them, positive opinions exceed 80%, reaching in some cases 100%.

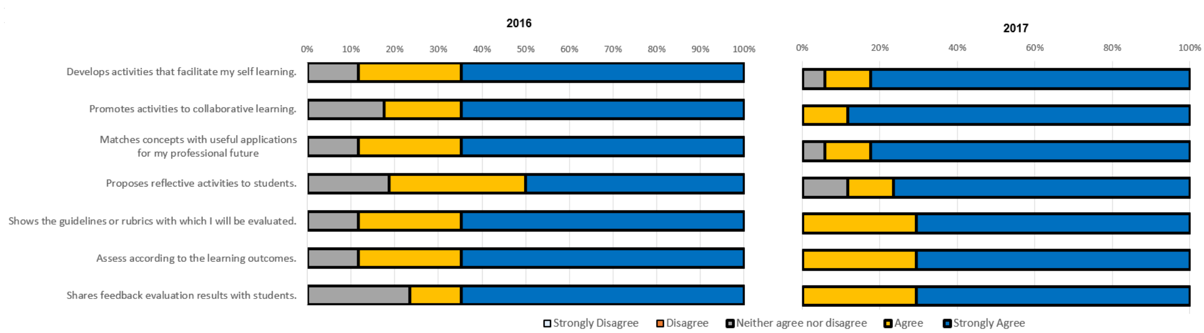

Figure 9. Teacher performance survey results (2016-2017).

DISCUSION AND CONCLUSIONS

Our preliminary results lead us to believe that the use of Flipped Classroom methods increases in-class student participation, because of their commitment to outside class work. The inclusion of practical activities also positively impact students' active participation and collaborative learning (CDIO standard 8). This leads to metacognition in students by making them aware of their learning process, and stimulates reflection in faculty about their teaching.

The Flipped Classroom model presented here is a generic and replicable proposal that can be applied to both regular and intensive courses in any disciplinary area in Higher Education. The model is a framework for promoting educational innovation and thus generating a positive impact on student learning. Even though the model relies on access to information technologies and 70% of our students belong to the first three quintiles, the educational resources are easily accessible by using low cost ubiquitous devices such as cellphones, tablets and notebooks available to most 21st century students (CDIO Standard 6).

Our results for the Strength of Materials course show that the incorporation of the Flipped Classroom methodology increases students' motivation and generates a greater student commitment to their learning process. This is consistent with Chen et al. (2014), in particular, with the positive student evaluation of the experience, in which they highlight the possibility of seeing the contents again and again through video and the development of in-class dynamic activities that allow them to clarify doubts and strengthen their learning.

Regarding the methodological innovations applied in the Programming Lab I during the last 4 years, the academic performance of the students has improved consistently. At the same time, the opinions students have of the teachers' performance have also improved. This is consistent with the teachers' self-perception about their pedagogical practices, motivating them to continue incorporating innovations that favor student learning (CDIO standard 10).

Some of the lessons learned from these implementations are:

- The pedagogical support given by the Flipped Classroom teaching community to the instructor is crucial. The pedagogical team should observe the instructor's practical in-class sessions the first time the model is implemented, in order to give him timely feedback, fostering reflection and allowing him to improve his pedagogical practice.
- It s more effective to use videos of maximum 10 minutes and to have reading materials of maximum 20 pages, which are more appropriate to the times students actually dedicate to audiovisual material review and autonomous study.
- The instances of communication between educational agents should be systematized so that they can evaluate the implementation and collect information on its advantages and difficulties. This allows adjustments and improvements to the educational processes, encouraging more reflective teaching and promoting a quality education.
- Including a media support group helps overcome the initial preparation time for creating high quality videos, which is a well known limitation of the flipped classroom method.

Our future research challenges are: designing effective mechanisms to allow transferring expertise to instructors less experienced in the implementation of b-learning methods; data gathering to determine this strategy's suitability to generate deep and durable learning; and measuring the metodology's impact on teaching competences via a phenomenological study.

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BIOGRAPHICAL INFORMATION

Claudia Martínez-Araneda studied Computer Science at the University of Concepción, Chile, and obtained her Master in Educational Informatics at the Universidad de la Frontera, Chile. Currently she is a faculty member in the Computer Science Dept. at UCSC, Chile. Her research and interest areas are Information retrieval and engineering education.

Matilde Basso studied Geology at the University of Concepción, Chile. Currently she is a faculty member in the Civil Engineering Dept.at UCSC, Chile, where she also serves as undergraduate program director. Her research areas are geology and engineering education.

Marcia Muñoz studied Computer Science at the University of Concepción, Chile, and obtained her M.C.S. at the University of Illinois at Urbana-Champaign, USA. Currently she is a faculty member in the Computer Science Dept.at UCSC, Chile, where she also serves as undergraduate program director. She leads the curriculum reform project for the Computer Science program. Her research areas are machine learning and engineering education.

Claudio Oyarzo studied Civil Engineering at Universidad Técnica Federico Santa María, Chile, and obtained his PhD in Civil Engineering at the University of Auckland, New Zealand. He is a faculty member in the Civil Engineering Dept. at UCSC, Chile, and he has served as civil engineering program director and School of Engineering head. His research areas are earthquake engineering, structural health monitoring and engineering education.

Corresponding author

Mg. Claudia Martínez-Araneda.
Universidad Católica de la Santísima Concepción
Alonso de Ribera 2850
56-41-234-5332
Concepción, Chile 4090541
cmartinez@ucsc.cl

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THE IMPACT OF IMPLEMENTING ONE PROGRAMME-WIDE INTEGRATED ASSESSMENT METHOD

Suzanne Hallenga-Brink, Wianda Visser

The Hague University of Applied Sciences, the Netherlands

Miranda de Hei

The Hague University of Applied Sciences &
University of Applied Sciences Utrecht, the Netherlands

ABSTRACT

In September 2017, the English-taught, 3-year Bachelor Industrial Design Engineering (IDE) programme at The Hague University of Applied Sciences (THUAS) has changed its curriculum from a linear to a flexible, choice-based modular curriculum, 'Curriculum M'. And with it, one integrated assessment method has been developed for the whole programme, centered around ownership of the students regarding their own learning, and assessing directly and holistically on competency-level. Students decide themselves which six sub-competencies they will prove mastery of, on what level (novice, advanced beginner, or competent), with what proof material from their portfolio library, during which integrated oral assessment (in week 5, 10 or 15 of a semesters). This oral assessment is the only summative method of testing offered throughout the programme. In this paper the first four iterations of the integrated assessment, which are all part of the only mandatory semester 'Basics of IDE' (Boi), are analyzed. Each 'real-time beta-testing' iteration was observed and reflected on, which lead to (minor) changes in the design to be implemented in the next iteration. The expectation was that the assessment redesign in the authentic, integrated project-based, active-learning IDE curriculum leads to an increase of students' ownership for their learning process, improvement of study progress, and more lifelong learning aptitude of students. The results of this study indicate that these goals were achieved.

KEYWORDS

Integrated assessment, flexible curriculum, oral assessment, competency-based learning, standards: 2, 3, 10, 11, 12

INTRODUCTION

The English-taught, 3-year Bachelor programme of Industrial Design Engineering (IDE) at The Hague University of Applied Sciences (THUAS) has changed its curriculum into a flexible, choice-semester-based curriculum in September 2017, named Curriculum M. The former, linear curriculum was already in active learning format, with authentic projects with real clients and users for students to learn to interact with. Each module of ten weeks offered such a project, supported with knowledge and skills courses and project tutoring. Students received feedback on their work and process during the first weeks, and also during assessments. Typically, students would have four assessments in week 8 and 9 of each module: delivering the project results to the client and tutors and doing assignments and/or written exams for each supportive course. The different assessment methods were aligned with the learning goals and activities. The project results were graded on both process and end result per group, with the possibility to deduct or add grade-points for individuals. Course work and exams could be either individually assigned or group work. In Curriculum M, the three years are divided into six 20-week semesters. After the first compulsory semester from September till February of year 1, students choose four semesters from a thematic menu, offering authentic either in-depth design challenges or multidisciplinary innovation challenges, with supportive workshops for knowledge and skill development. They finish with a graduation project semester at a company, organization or the student’s own enterprise.

Problems with assessment in the linear curriculum

The linear curriculum of IDE scores high on CDIO-standards such as the context, learning outcomes, integrated curriculum, introduction to engineering, design-implement experiences, integrated learning experiences, active learning, and learning assessment. Nevertheless, several problems related to the programme’s assessments exist. First of all, study progress is far from optimal. Drop-out rates after the first year of studies in the linear curriculum are around 19%. Around 40% of all first-year students in the past three years got their propaedeutic diploma in 1 year (which means all credits offered that year), and around 50% of all first-year students manages to finish the 3-year programme within 4 years (Visser, Hallenga-Brink & Kok, 2018). Although these percentages are not uncommon for Dutch undergraduate engineering education, IDE has a need to improve the assessment system in order to improve student success rates. Students in the linear curriculum show difficulty to prepare simultaneously for 4 assessments at the end of the module and pass them all. Often group stakes are prioritized, and the project results are delivered, but individual assignments and most often written exams suffer. Either students try without preparation for the latter, in case they may pass after all, or plan in advance to do the exam at the resit-moment ten weeks later (one week after the assessments of the next module). Some students pass the group work, benefitting from the group level, but have more difficulty with the individual work. These occurrences cause study delays, negative binding study advices (when the minimum of 50 EC has not been reached within a year) and drop-outs.

Secondly, IDE offers competency-based education. However, assessment in the supportive courses is done on course-specific learning goals of knowledge or skills. The competency profile of IDE has been redefined in 2015 in accordance with the national professional profile for industrial design and the CDIO syllabus. This was done to reflect which personal and interpersonal skills, and integration of knowledge and skills within an external context, students need to develop to become futureproof ‘designers who can design’ (Dekkers, Glerum, & Hallenga-Brink, 2015). After implementation, in 2016, a matrix of the coverage of the redefined competency profile sub-competencies and the learning goals of the different courses and projects of the linear IDE curriculum showed that some sub-competencies were partially assessed as often as nine times during the programme, while others were only touched upon indirectly once. There is no clear overview of how and when students prove the total of 24 sub-competencies on the 3 pre-defined levels (novice, advanced beginner, competent).

And thirdly, although the project work in the curriculum is authentic with real clients, the assessment design is not authentic. Standard 11 of CDIO focuses on the assessment of student's learning of not only disciplinary knowledge, but also personal, interpersonal, and creation skills (Crawley et. al., 2011). The standard describes how for different kinds of learning outcomes, different kinds of assessment methods need to be chosen, in order to achieve constructive alignment between learning goals, learning activities and assessment (Biggs & Tang, 2011). The varied array of possible assessment methods includes written tests, oral tests (one-on-one exams, presentations), portfolios with (collected) assignments, reports, observations, student reflection etc. These assessment methods aren't equally authentic, when it comes to offering students ways of learning including assessment which are congruent with what their professional engineering career will look like (Mazur, 2013). At IDE, the majority of students direct their activities towards what is asked of them in the assessments, focusing on what (they think) the teachers want them to show, instead of focusing on what innovation really needs. This withholds students from learning the profession in-depth and initiating the process of lifelong learning, while using their talents. A solution would be to start asking those things at the assessment instead, so 'checking the boxes' ensures this necessary proof of competency.

Assessment in the modular Curriculum M

The flexible, choice-based modular curriculum, Curriculum M, has been developed in co-creation with teaching staff, students, alumni and the work field (Hallenga-Brink & Sjoer, 2017). The main vision underlying the flexibility is to educate students who can maneuver in our transitional society once graduated, able to combine their unique talents and interests to become an expert in new areas repeatedly, as each different design challenges demands.

Students learn to master the five main competencies described in 24 sub-competencies on three pre-defined levels, which are the center of the integrated assessment system. The ownership of the learning lies with the students themselves. They prove their sub-competency mastery during one-hour, integrated, oral assessments, which are offered at a 5-week interval, three times per semester. Each assessment is worth 10 out of the 30 EC of the semester. Research shows that students typically start to prepare for an assessment three to four weeks beforehand (Kerdijk, Cohen-Schotanus, Mulder, Muntinghe, & Tio, 2015), so the 5-week intervals will make students study more frequently and prevail procrastination. Also, this research shows that when there is no rivalry of learning activities, students can focus completely and individually on passing a test and results improve. In the assessment weeks there are no classes and no project tutoring, nor any other assessments scheduled. Students pick the time and day themselves for the session from a list, making sure they will not be assessed by their own coach/project tutor. The implementation phase proved there were no scheduling problems, as students followed their own preferences for choosing time slots at the beginning or end of the assessment week, early in the day or later, and at which assessor duo.

The first semester 'Basics of IDE' (Boi) differs slightly from the other semesters: it is compulsory, and instead of three there are four integrated assessments (for 6, 8, 8 and 8 EC). The first assessment in Unit 1 is a smaller version: students need to prove 3 sub-competencies only for a pass. This is done to ease students into the assessment system. Since 90% of the student population is international, all have just started life as a student, and so far, most have not needed to take ownership of their own learning process yet in the way IDE asks them to.

There are two assessors present at the integrated assessments, who use the programme-wide professional competency rubric, with semester specific indicators that translate how students can prove that particular sub-competency within the context of the chosen semester. This rubric is known and communicated to the student from the beginning of the semester. Students use their contributions to the – authentic, highly challenging, complex, teamwork – project work of the semester, as proof of their sub-competency development. They collect these in a personal portfolio library. The programme applauds students for experimenting and teaches them that failure is part of innovation. Accordingly, the end results of a project are not graded summatively, but only formatively during the workshops, tutoring and the week 15 exposition. It is the process and the ability to reflect on that process that counts. The oral assessment is similar to a conversation a junior designer has with his creative director in a design studio, or project leader in an engineering company. It is based on the portfolio library work the students upload beforehand, including sketches, deliverables, documents, group session results, presentations etc. The students discuss their work and learning process, reflect, answer questions and receive feedback and tips for continuation.

The question is, will this redesign of the assessment of the authentic, project-based, active learning IDE curriculum lead to improvement of student ownership, study progress, and lifelong learning aptitude of the student?

METHOD

A mixed-method educational design research approach is used (McKenney & Reeves, 2012). The integrated assessment design is implemented in the programme, and iteratively prototyped while making the effort to understand and improve what happens. By frequent evaluation and reflection in the iterations, changes are made to the design and implemented in the next iteration. In this paper, the first four iterations, which were all part of the compulsory first-year semester (Boi), are analyzed.

Student Ownership & Study Progress

Data from the student information system Osiris, which THUAS uses for all grade registration, is used to measure the effectiveness of the intervention of implementing the integrated assessment method in the IDE curriculum. The study results of the first half year of the programme from three cohorts (two linear curriculum cohorts 1516 & 1617, and one modular curriculum cohort 1718) are analyzed. Student ownership is measured by the number of students who show up for their first assessment. Study progress is measured by the number of assessments passed at the 1st of February of the first year of studies and the average scores on the assessments, as well as the number of students who still have resits open and the number of resits in total per course. Students who drop out in the first weeks of the programme before being assessed are not taken into account, as their choice was not related to the assessments.

Lifelong Learning Aptitude

Observations of the four iterations of implementing the integrated assessment method are summarized by the improvements and alterations made in the assessment principles and procedure. The initial principles and procedure are the result of a co-creation process by the IDE teaching staff, educational services from the university, and an independent educational advice agency. Also, other faculties were consulted and their common practices and challenges in oral exams have been taken along in the decisions. During the four iterations, improvements were made based on the output of the following teaching staff team sessions:

- Initial grading rubric formulation: semester specific indicators and portfolio library suggestions (before the semester)
- Grading rubric improvement based on workshop details (in the first week of each Unit)
- Trial assessments: these were think out loud sessions with two assessors and students in presence of all students, (week 4 of Unit 1, 2 and 3)
- Calibration of interpretation of the indicators by assessors (after Unit 1, before Units 2, 3 and 4): The calibration-session with assessors in Unit 1 was a brief walk-through through the grading form. In Unit 2 the assessors looked back at how they had interpreted the rubric during the assessments of Unit 1, and another brief walk-through was organized for the next assessment. In Units 3 and 4 the sessions were also done before the assessment with the workshop lecturers present to share what they had done/would do with the students and what assessors could see back during the assessments.
- Feedback amongst co-assessors based on recordings (after Unit 1, 2 and 3)
- Feedback to co-assessors based on the week 6 semester student-evaluation (quality cycle) plus the discussion of the results with students in class), plus the feedback sent by three students on their assessment, including one request to be re-assessed.

The improvements made are used to establish the ability to facilitate the development of lifelong learning strategies by the assessment method.

RESULTS

Study results of 3 cohorts in the first half year of the programme

It is THUAS policy to offer each assessment twice per year. IDE offers a first chance and a resit 10 weeks later in the linear curriculum, and (all) resits in week 18 in the modular curriculum. In Table 1 the attendance at the first assessment opportunity is listed per cohort, as well as the average score per assessment, their pass rate in percentage, and the number of resits which remain open, all halfway the first year, at the start of the new module/semester. The number of students is included, as some students have several resits open. The pass rates for the modular curriculum show the percentage at first attempt plus the percentage after the resit.

Table 1. Study Results of the First Half Year of the Programme

Linear Curriculum	**Cohort 1516**		54 students, excl. 7 who stopped in the first weeks 11%)	
	Attendance at assessment %	Average score	Pass rate %	Nr of resits open halfway the year
Assessments week 8-9		(max. 10)		29 students:
Project Communities	98%	8,3	96%	2
Personal Branding	94%	7,4	94%	3
Cultural Differences	98%	8,7	98%	0
Visualization Communication 1	94%	6,6	93%	4
Assessments week 18-19				
Project Future	87%	7,7	87%	7
Basics of Technology	98%	8,5	96%	0
Mechanics & Mathematics	56%	7,7	56%	23
Visualization Communication 2	76%	6,7	73%	16
Linear Curriculum	**Cohort 1617**		71 students, excl. 9 who stopped in the first weeks (11%)	
	Attendance at assessment %	Average score	Pass rate %	Nr of resits open halfway the year
Assessments week 8-9				41 students:
Project Communities	100%	6,7	94%	8
Personal Branding	100%	7,1	94%	4
Cultural Differences	99%	7,1	89%	8
Visualization Communication 1	90%	5,6	80%	14
Assessments week 18-19				
Project Future	86%	7,0	83%	12
Basics of Technology	83%	7,0	79%	15
Mechanics & Mathematics	58%	4,1	46%	38
Visualization Communication 2	73%	4,6	59%	29
Modular Curriculum	**Cohort 1718**		33 students, excl. 4 who stopped in the first weeks (11%)	
	Attendance at assessment %	Average score	Pass rate %	Nr of resits open halfway the year
Assessments week 5				2 students:
Integrated assessment Unit 1 project micro mobility: design methodology, user research, team dynamics, prototyping, product sketching	95% (35 from 37)	6,5	76% - 94%	2
Assessments week 10				
Integrated assessment Unit 2 project micro mobility: design methodology, construction, materials & manufacturing, prototyping, product sketch	91% (32 from 35)	7,2	82% - 97%	1
Assessments week 15				
Integrated assessment Unit 3 project micro mobility: design methodology, business, manufacturing & economics, rapid prototyping, product sketching	100% (all 33)	7,7	84% - 97%	1
Assessments week 19				
Integrated assessment Unit 4 project portfolio: design methodology, personal branding, portfolio design, product sketching	93% (31 from 33)	7,4	86% - resits yet to come	n.a.

While first-test-moment attendance rates in the linear curriculum declined within the first half year, in the modular curriculum they increased to 100%. The average scores on assessments also show an increase, despite the growth in number of sub-competencies that have to be proven. Although in the linear curriculum projects and certain supportive courses had high success rates as well, there were also some courses with typically had many resits still open after the first half year, such as Mechanics & Mathematics and Visualization Communication. The data shows that some students had many resits left. They were unable to show sufficient level in individual assignments but passed group-graded courses and projects. The four iterations of the Curriculum M assessment proved this ‘hitchhiking’ is no longer possible. Although a student can bring group work to an oral assessment, presenting what happened and answering questions about it takes understanding and involvement of the process. The one student, who again needs to resit three integrated assessments after the resits in week 18, is such an example. Chances are high for this student to get a negative binding study advice at the end of the first year (when passing less than 50EC). 94% of the Curriculum M students will not have to deal with rivaling activities of resits during regular semester activities during the next semester, which in chain reaction improves the chances of success for them. The percentage of students getting their propaedeutic diploma in one year is expected to be bigger this year than the 40% of the previous cohorts.

Changes in the assessment guidelines and procedures along the 4 assessment rounds

In table 2 the iterative improvements of the guidelines throughout the 4 iterations can be seen.

Table 2. The integrated assessment guidelines iterations

Principles for Integrated Assessment in Curriculum M	Moment added/changed	Remarks
Points of departure		
Nominal = normal	Before Unit 1	
Every student is assessed individually.	Before Unit 1	
We expect every student to seriously attempt to pass first try.	Before Unit 1	
There is room for experiment and failure, as long as there is reflection and (suggestion for) adjustment.	Before Unit 1	Re-established after Unit 1, some assessors were inclined to assess quality of end results
Ownership of assessment		
The student is owner of his learning process and results.	Before Unit 1	
Students plan and choose which sub-competencies (SCs) at what level they will prove at what assessment during the semester. In Boi the first two Units are pre-set, to ease students in. In Unit 3 and 4 students choose 5 out of 6 pre-set options.	After Unit 2	Unit 2 proved to be too soon for this, students unsuccessfully tried to prove all 6 SCs, without choosing
The programme-wide competency rubric is complemented with semester-specific indicators for all sub-competencies at the start of the semester, so students can plan	After Unit 4	It was in the design, but not made explicit
The indication of possible portfolio library elements for proving SCs, nor the suggested elements of the indicators, is not a compulsory list to be checked off one by one. They are suggestions, and not an exhaustive list. Indicators should be written on (holistic) competency-level.	After Unit 2	The indicators of Unit 2 were inclined that way, making students just do what the list said, instead of showing their complete, integrated efforts for the project
Students upload their portfolio library work on Blackboard before their assessment	After Unit 1	Next to the audio recordings, this needs to be archived
During the assessment		
There is 60 minutes of assessment time per student.	Before Unit 1	Some assessments in Unit 1 lasted up to 90 minutes, others limited the student to the 60 minutes as was the plan. After Unit 1 the assessors agreed all students get 1 hour of time, no more. Within that hour differences are possible, as some students need more time for feedback, some assessors less time to prepare etc.
A student is always assessed by 2 assessors.	Before Unit 1	The duos were mixed a lot in Unit 1, so assessors would learn with and from each other. This was beneficiary and kept all through Boi
Coaches and tutors don’t assess their own students	After Unit 3	At first it said ‘coaches’ only, who have a double role in Boi as tutors. In other semesters the independence of assessment should be kept this way
There is a clear structure for the oral assessment for both assessors and student.	Before Unit 1	
Assessors ask 1 transparent and clear question per question. Don’t hide 3 questions in one and don’t trick the students with your questions.	Before Unit 1	
Grading/assessment should build confidence, not take it away. (We help students manifest and realize what they CAN do (not cannot do).	Before Unit 1	Needed re-establishment after Unit 3, where students noticed some assessors were focusing on mistakes they made instead
Grading/assessment should be a dialogue.	Before Unit 1, after Unit 4	After Unit 1 it has been suggested to do the grading with the student present in the room, instead of in the hall-way. Once assessors are more experienced this may be the next step next year.
If things don’t go as planned		
For students with special circumstances, extra care can be arranged (in advance) via the student dean.	Before Unit 1	Extra care arrangements executed: let students choose their own assessors, students are allowed to videotape their 10-min. presentation
In case of unfortunate circumstances there is one resit moment in week 18 (+ week 19 in S+1 for Boi Unit 4).	Before Unit 1, after Unit 4	The resits in week 18 did not work in Boi, because there were Portfolio Design classes. This needs adjustment for next year.
If a student disagrees with his grading, or the routine during his assessment, he can ask for reconsideration. Two fellow assessors listen to the recording and look at the student’s portfolio library, and give the initial assessors feedback. Then they talk to the student and possibly reconsider the grading, or give extra feedback for the resit	After Unit 2 and 3	Four cases spread over the Units gave cause for this guideline

Some of these improvements lead to an increase in the aptitude of students to develop lifelong learning competencies. Examples are the room to experiment and fail, yet show the learning in that process; the improved scaffolds for the process of choosing the sub-competencies you want to develop in and show during your assessment; the fine-tuning of the indicators to keep students in deep-learning strategies instead of checking the boxes; and the dialogue during the grading process which will be implemented in the next run of Boi.

The procedure's additions and improvements through the Units

In table 3 the same process of iterative improvement is depicted for the procedure of the integrated assessment itself. Like the information in table 2, this procedure was shared with students beforehand, and alterations were communicated during the semester.

Table 3. The integrated assessment procedure iterations

Procedure Integrated Assessment		**Remarks**
In advance		
-2/3 weeks	Students sign up for a specific timeslot on the lists in area 5.	Next year the signing up process will be digitalized.
-1 weeks	On Wednesday the assessors are appointed to each student and the timeslots are closed. Students can no longer swop.	After Unit 1, the assessor duos were added to the slots first and students enrolled to a time slot with designated assessor duo.
1 day in advance	Student uploads his portfolio library work on Blackboard	After Unit 1 this was deemed necessary and added. A number of students uploaded their work from Unit 1 in hindsight.
1 hr in advance	Student is present at university, to make sure trains or flat tires don't stand in his way.	This worked well
During assessment		
5 min	Start of the assessment, student installs work in assessment room.	After Unit 1: Because of limited rooms available, a desired double room set-up is not possible
10 min max.	Assessors look through student's work while student waits in the hallway.	After Unit 1: if assessors need less time, they are allowed to start with the oral part early.
30 min	Oral assessment, student shows his level of mastery. Student starts with a short (10 minutes max.) presentation, answers questions and gets feedback. The assessment is recorded (audio) for archiving purposes.	After Unit 1 the presentation was added, as not all assessors gave students room for it. After Unit 2 it was decided the presentation could be filmed in advance and shown, for those students who were nervous or less easy talkers.
10 min	Assessors confer about the results while student waits outside the room.	After Unit 1 the idea rose to keep the student in the room, for transparency of grading reasons. Not all were comfortable yet with this idea.
5 min	Results are made known to the student, closing of the assessment.	After Unit 2: when not in agreement with the student, 5 minutes is very short. Also: ask students to take notes of the feedback, and ask him to repeat what he takes home from the feedback and how he will implement this in the next unit.
After assessment		
same week	Assessors register results on Blackboard.	Although this didn't always happen, the team agreed this should remain the rule.
+1 weeks	Semester coordinators process results in Osiris.	After Unit 4: in the near future SCs can be put in Osiris, in which case the assessors can do that themselves directly.

The process of signing in for a certain timeslot proves to functions as the start of the ownership the student feels for having his learning path assessed. Lifelong learning competency is practiced in making decisions on what materials to use as proof, and what to tell about it, instead of checking off a pre-formulated list of deliverables. The student has to decide for himself when he has been ample thorough in his learning endeavors. He practices being on time, structuring the oral assessment, manifesting himself, taking notes of the feedback, and implementing that feedback in planning the next learning activities. All of these are independent activities in the learning context, which the student will be doing as a designer after graduation as well.

CONCLUSION & DISCUSSION

The first four runs with the integrated assessment system show that the choice for one single, integrated assessment format for the whole programme has a substantial impact on the learning behavior of students. The noteworthy increase in attendance of the first assessment moment in the modular curriculum, compared to the linear curriculum, shows students feel more ownership for their own learning, and study progress has improved. As Kerdijk et. al. (2015) indicated, students proved to be facilitated better to persevere and pass all their assessments at first try, with is no rivalry of assessments of other courses, and less room for procrastination due to the 5-week interval.

The set-up of the assessment appeals to the emerging lifelong learning competencies of the student. From the first assessment onwards, students are asked to talk about their work, whether satisfied about it or not, manifest themselves, reflect on their learning, indicate what they will do next, where they want to dive deeper. The choices they have to make help both motivation and the development of a professional identity during their studies (Reekers, 2017).

As the approach chosen for the implementation of the integrated assessment was one of 'real-time beta-testing' and 'learning on the job', and for many lecturers it was a new approach, the calibration sessions and trial assessments - although hard to schedule - were a must. As assessors get more experienced, it will get easier to work with the complete competency rubric and estimate the level of students in a way that is close to other assessors. The advantage of this approach is that lecturers learn more about what each of them does in class, and thus can support the student with more integral feedback as well.

For the purpose of this study, only the impact of the programme-wide integrated assessment on student ownership, study progress and lifelong learning competencies were considered. There are more beneficial factors of influence at work, such as the flexibility, the freedom of choice for semesters, and the authentic projects in which students work with real clients and users. These can be studied as the curriculum progresses. Also, the first cohort of Curriculum M is smaller than a typical IDE cohort and students are halfway the first year of the programme. Therefore, the amount of data is limited. The same data analysis could (need to) be repeated and expanded in the semesters to come. None the less, the results give good hopes for the future.

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BIOGRAPHICAL INFORMATION

Suzanne Hallenga-Brink, *M.Sc. M.Sc.* is senior lecturer and Head of Industrial Design Engineering. She has an interdisciplinary background in Industrial Design Engineering and Educational Sciences. She is currently one of the European Regional Leaders of CDIO. Her current research focuses on the design principles of an innovative curriculum to decrease underachievement and facilitate sustainable talent development in higher design education.

Wianda Visser*, M.Sc.* is Program Director of Industrial Design Engineering and Strategic Leader of Internationalization of the Faculty. She has a background in Educational Sciences and Health Sciences. Her research focuses on innovative education to stimulate student talent development and create an appreciative working climate where teachers experience to be effective from a broad perspective.

Miranda de Hei *PhD* is a senior researcher at The Hague University of Applied Sciences and a senior lecturer and researcher at HU University of Applied Sciences, Utrecht, the Netherlands. Her PhD was titled “Collaborative learning in higher education: design, implementation and evaluation of group learning activities”. Her current research focuses on curriculum design of group learning, networked learning and professional learning communities.

Corresponding author

Suzanne C. Hallenga-Brink
The Hague University of Applied Sciences
Faculty Technology, Innovation and Society
Johanna Westerdijkplein 75,
2521EN The Hague, The Netherlands
+31 70 445 7717
s.c.hallenga-brink@hhs.nl

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DEVELOPMENT AND IMPLIMENTATION OF THE CDIO APPROACH IN KUBAN STATE TECHNOLOGICAL UNIVERSITY

Alexander Chuchalin, Tatyana Barkhatova, Svetlana Kalmanovich

Kuban State Technological University, Krasnodar, Russia

ABSTRACT

The paper presents undergraduate, graduate and postgraduate engineering programs of the Kuban State Technological University redesigned as “engineering triads” based on the CDIO Standards, as well as on the FCDI and FFCD models, developed as a result of the CDIO approach evolution. The methodology for developing the FCDI and FFCD models is based on the specifics of engineering activities of the MSc and PhD program graduates. In the continuation and extension of the CDIO model mostly focused on complex engineering activity of the BEng program graduates, the FCDI and FFCD models consider innovative engineering activity and research engineering activity as priorities for MSc and PhD program graduates, respectively. The CDIO Standards and newly developed FCDI and FFCD Standards were used for the design of undergraduate, graduate and postgraduate engineering programs ensuring the consistency and continuity of the 3 cycles of graduate training for complex, innovative and research engineering activities.

KEYWORDS

Engineering programs, cycles, redesign, evolution, CDIO Standards: 1 – 12.

INTRODUCTION

Kuban State Technological University (KubSTU) is one of the largest research, educational and cultural centers in the South of Russia (http://kubstu.ru/en). The University trains engineers for high-tech industry and offers 31 undergraduate programs, 26 graduate programs and 56 postgraduate programs. In January 2018, at the CDIO European Regional Meeting KubSTU was presented as a potential collaborative member of the Worldwide CDIO Initiative.

One of the most important challenges for KubSTU in the near future is the modernization of undergraduate (BEng), graduate (MSc) and postgraduate (PhD) engineering programs based on the CDIO Standards, as well as on the FCDI (Forecast, Conceive, Design, Implement) and FFCD (Foresight, Forecast, Conceive, Design) models developed as a result of the CDIO approach evolution (Chuchalin, Daneikina and Fortin, 2016, Chuchalin, 2018).

The redesign of KubSTU engineering programs will be carried out in the conditions of bringing programs in line with the requirements of the new version of the Russian Federal State Educational Standards (FSES 3++) introduced in 2017 (http://fgosvo.ru/fgosvo/151/150/24). A peculiarity of the process is as follows: BEng, MSc and PhD engineering programs will be redesigned *simultaneously* as "*engineering triads*". The main idea is to ensure the *consistency* and *continuity* of training of graduates of programs of 3 cycles to *complex*, *innovative* and *research* engineering activities, respectively.

The process of modernization of KubSTU engineering programs will be carried out progressively. To start with, "engineering triad" in the field of Food Production Technologies is to be redesigned. Engineering programs leading to BEng, MSc and PhD degrees in "Technologies of food production from plant raw materials" (specialization: oil & fat, and perfume-cosmetic products) have been selected as pilot programs. The CDIO model is well known and widely used for the design of undergraduate engineering programs (Crawley et al., 2014). The FCDI and FFCD models were developed recently by analogy with CDIO model to ensure *better adaptation* of the CDIO approach to *graduate* and *postgraduate* engineering education (Chuchalin, 2018).

FCDI MODEL

The *FCDI (Forecast, Conceive, Design, Implement)* model was developed to design *graduate* (MSc) engineering programs. A FCDI program is based on the principle that *innovative* product, process, and system lifecycle design and development – Forecasting, Conceiving, Designing and Implementing is an adequate competence model. The "Forecast" stage includes analyzing the market trends; making predictions of future customer needs; estimating risk and uncertainty; determining the most demanded and competitive innovative products, processes, and systems. The "Conceive" stage includes feasibility study; modelling and simulation; development of advanced technique and technology; assessment of the economic impact of innovations; planning and creation of R&D resources for innovative product, process, or system design. The "Design" stage focuses on designing & developing of innovative product, process, or system taking into consideration severe limitations. The "Implement" stage mainly refers to the production management when implementing innovative projects, as well as controlling of advanced technology when manufacturing and coding. The absence of "Operate" stage in the FCDI model indicates that this kind of engineering activity (operation and maintenance of products, processes and systems) is not a priority for MSc program graduates.

The FCDI Syllabus v1, as a result of the evolution of the list of learning outcomes (LOs) presented in the CDIO Syllabus v2 (Crawley et al., 2014), was developed recently (Chuchalin, 2018). It focuses the attention of the MSc engineering program designers on the need to provide Masters with a deeper interdisciplinary scientific and technical knowledge (i.e. in-depth knowledge of mathematics, natural and engineering sciences; methods of innovative activity), as well as professional competences to forecast customer needs in innovations and to conceive, design and implement new products, processes and systems (i.e. analytical study and solution of innovative problems; systematic innovative thinking; forecasting and innovation management; leadership in innovative technical enterprise; innovative technological entrepreneurship, etc.).

The FCDI Standards v1 were developed as a result of the evolution of the CDIO Standards (Chuchalin, 2018). In particular, they focus the attention of the MSc engineering program designers on integrated curriculum with mutually supporting interdisciplinary courses, innovation activity with an explicit plan of integration of personal and interpersonal skills, and innovative product, process, and system design and development skills based on forecasting the stakeholders' needs (Standard 3 FCDI). The essential elements of the curriculum should be an introductory workshop that provides the framework for engineering practice in innovative product, process and system design and development based on forecasting the needs of stakeholders (Standard 4 FCDI); innovation-design experiences (Standard 5 FCDI); teaching and learning based on active and innovative methods (Standard 8 FCDI).

FFCD MODEL

The *FFCD (Foresight, Forecast, Conceive, Design)* model was developed to design *postgraduate* (PhD) engineering programs. A FFCD program is based on the principle that *creation of scientific basis* for the development and design of innovative product, process, and system lifecycle – Foreseeing, Forecasting, Conceiving and Designing is an adequate competence model. The "Foresight" stage includes future study; long-term vision; analyses of the society needs; research & innovation planning; technological foresight; analyses of "critical" technology. The "Forecast" stage includes knowledge management; research and new knowledge generation; critical analyses of scientific data; assessment of knowledge-intensive technology needs. The "Conceive" stage includes creation of scientific basis for the development and design of innovative product, process, or system; development of new technique and technology based on up-to-date knowledge. The "Design" stage focuses on scientific support of knowledge-intensive innovative product, process, or system design and development. The absence of "Implement" stage in the FFCD model indicates that participation in the production of products, processes and systems is not a priority for PhD program graduates.

The FFCD Syllabus v1 was developed as a result of the evolution of the list of LOs presented in the FCDI Syllabus v1 (Chuchalin, 2018). It focuses the attention of the PhD engineering program designers on the need for PhD-holders to acquire new scientific and technical knowledge (basic and applied sciences; engineering and research methods), as well as professional competences to create scientific basis for the development and design of innovative product, process, and system (i.e. analytical study and solution of scientific problems; experimentation, research and generation of new knowledge; systematic scientific thinking; critical analysis of the existing scientific data and results of own research; foresight and research management; leadership in the research enterprise, as well as research entrepreneurship, etc.). The acquisition of pedagogical competences is also important for graduates of PhD programs.

The FFCD Standards v1 were developed as a result of the evolution of the FCDI Standards v1 (Chuchalin, 2018). In particular, they focus the attention of the PhD engineering program designers on integrated curriculum with mutually supporting transdisciplinary courses, research and pedagogic activities with an explicit plan of integration of personal and interpersonal skills, abilities to create scientific basis for innovative product, process, and system design and development using the methods of technological foresight (Standard 3 FFCD). The essential elements of the curriculum should be an introductory seminar that provides the framework for engineering practice in creation of scientific basis for innovative product, process, and system design and development (Standard 4 FFCD); research-design experiences (Standard 5 FFCD); teaching and learning based on active and research methods (Standard 8 FFCD).

BENG PROGRAM CURRICULUM DESIGN

The objectives of the BEng program "Technologies of food production from plant raw materials" based on the KubSTU mission and the CDIO Standards are as follows:

1. Graduates should have world-class competences and high civil responsibility necessary for *complex* engineering activity in the field of food production from plant raw materials.
2. Graduates should be able to solve *complex* engineering problems associated with food production to ensure the technological development of the Kuban Region and Russia.
3. Graduates should be able to conduct engineering activity at the stages of *conceiving, designing, implementing* and *operating* of food production technologies.
4. When *conceiving* graduates should be able to study the needs of consumers, assess the technological capabilities, determine the production strategy, carry out conceptual, technical and business planning.
5. When *designing* graduates should be able to take into account the needs of consumers and technological capabilities of production, create technological documentation, develop algorithms and product descriptions.
6. When *implementing* graduates should be able to use advanced materials and techniques, develop appropriate software, conduct testing and verification of products.
7. When *operating* graduates should be able to use modern food technologies, comply with the standards of health protection, environmental safety and provide recycling of products with the cessation of its harmful effects on the environment.

The diagram in the Figure 1 illustrates orientation of the 4-year (240 ECTS) BEng program LOs to C-D-I-O stages of complex engineering activity. It follows from the diagram that 15% of intended LOs (36 credits) will provide graduate competencies required for activity at the "Conceive" stage, and 25% of LOs (60 credits) are focused on the "Design" stage. The areas of priority for BEng graduates are "Implementation" (30% of LOs or 72 credits) and "Operation" (30% of LOs or 72 credits).

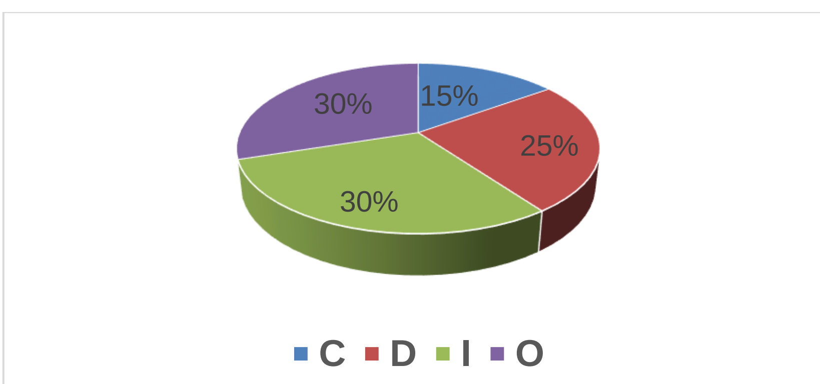

Figure 1. Orientation of BEng program intended LOs to C-D-I-O stages of complex engineering activity

The designers of BEng program have used the methodology developed within the framework of the implementation of the joint TPU-SKOLKOVO project of modernization of undergraduate engineering education on the basis of international standards (Chuchalin, 2013).

Table 1 shows the structure of BEng program corresponding to the C-D-I-O orientation (Figure 1) and meeting the FSES 3++ requirements. The program consists of three blocks of curriculum elements. Block 1 includes disciplinary (BEng1 – BEng3) and interdisciplinary (BEng4 and BEng5) modules, Block 2 provides internship (BEng6), and Block 3 includes the final project, as well as the final examination (BEng7). The program is implemented in two phases. In the first phase (1^{st} and 2^{nd} years of study), mainly general scientific and general engineering training is provided. In the second phase (3^{rd} and 4^{th} years of study), professional training is provided, taking specialization into account.

Table 1. The structure of BEng program in ECTS credits

	Block 1					Block 2	Block 3
	Disciplinary modules			Interdisciplinary modules		Internship	Final project & exam
	BEng1	BEng2	BEng3	BEng4	BEng5	BEng6	BEng7
First phase of training	21	54	22	6	8	9	-
Second phase of training	9	6	3	20	58	15	9
BEng1 – module of social sciences & humanities BEng2 – module of natural sciences & mathematics BEng3 – module of basic engineering science BEng4 – module of mandatory courses BEng5 – module of variable courses							

The diagram in the Figure 2 shows the contribution of BEng program modules to LOs focused on C-D-I-O stages of complex engineering activity. It follows from the diagram that the greatest contribution to the preparation of graduates to activity at the “Conceive” and “Design” stages is made by module BEng2 (natural sciences & mathematics), followed by module BEng1 (social sciences & humanities) and module BEng3 (basic engineering science).

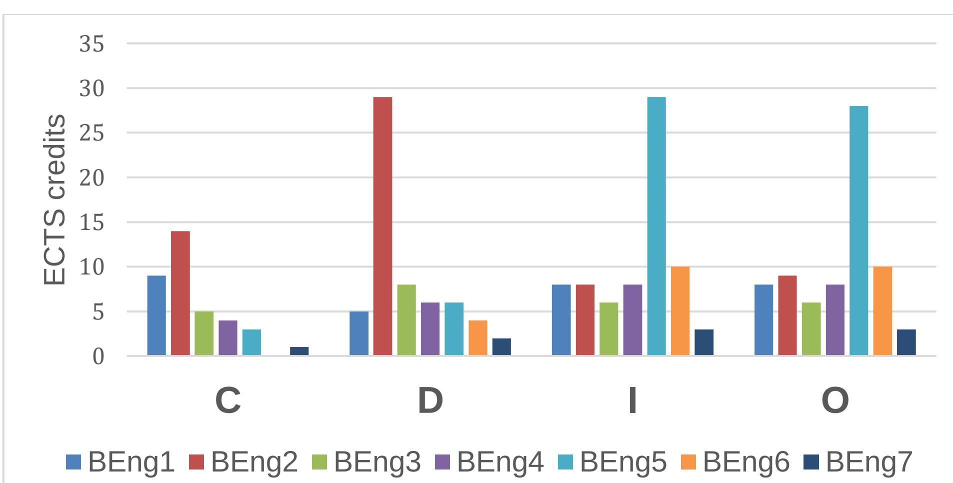

Figure 2. The contribution of BEng program modules to LOs focused on C-D-I-O stages of complex engineering activity

The greatest contribution to the preparation of graduates to activity at the “Implement” and “Operate” stages is made by module BEng5 (variable courses), followed by module BEng6 (Internship). At the same time, it follows from the diagram that each module of the integrated curriculum contributes to the preparation of BEng program graduates for complex engineering activity at all stages.

MSC PROGRAM CURRICULUM DESIGN

The objectives of the MSc program “Technologies of food production from plant raw materials” based on the KubSTU mission and the FCDI Standards are as follows:

1. Graduates should have world-class competences and high civil responsibility necessary for *innovative* engineering activity in the field of food production from plant raw materials.
2. Graduates should be able to solve *innovative* engineering problems associated with food production to ensure the technological development of the Kuban Region and Russia.
3. Graduates should be able to conduct engineering activity at the stages of *forecasting, conceiving, designing* and *implementing* of food production innovative technologies.
4. When *forecasting* graduates should be able to analyze trends in the market, investigate prospective customers' requests, assess risks and uncertainties, determine the most demanded and competitive products.
5. When *conceiving* graduates should be able to assess the high-tech capabilities, determine the innovative production strategy, create R&D resources for innovation design, assess economic impact of innovations.
6. When *designing* graduates should be able to focus on the consumer needs and high-tech capabilities, design and develop innovations taking into consideration severe limitations.
7. When *implementing* graduates should be able to manage production process and control advance technology.

The diagram in the Figure 3 illustrates orientation of the 2-year (120 ECTS) MSc program LOs to F-C-D-I stages of innovative engineering activity. It follows from the diagram that 20% of intended LOs (24 credits) will provide graduate with competencies required for activity at the “Conceive” stage, 25% of LOs (30 credits) are focused on the “Implement” stage and 25% of intended LOs (30 credits) are focused on the “Forecast” stage. The area of priority for MSc graduates is the “Design” stage (30% of LOs or 36 credits).

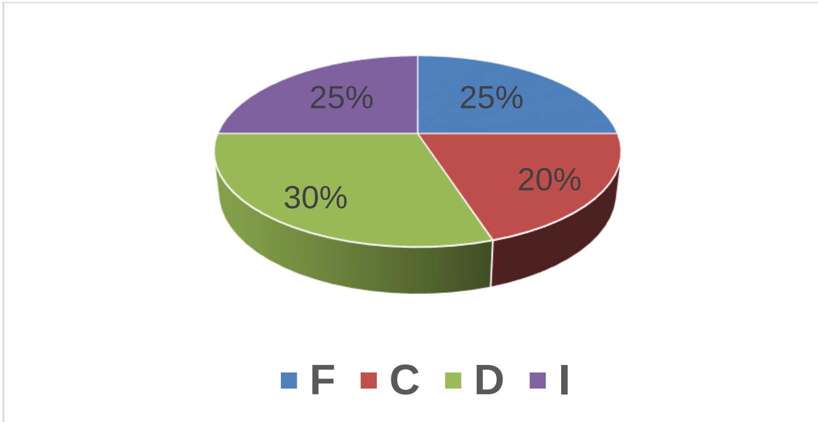

Figure 3. Orientation of MSc program intended LOs to F-C-D-I stages
of innovative engineering activity

Table 2 shows the structure of MSc program corresponding to the F-C-D-I orientation (Figure 3) and meeting the FSES 3++ requirements. The program consists of three blocks of curriculum elements.

Table 2. The structure of MSc program in ECTS credits

	Block 1				Block 2	Block 3
	Disciplinary modules		Interdisciplinary modules		Internship & research	Final project & exam
	MSc1	MSc2	MSc3	MSc4	MSc5	MSc6
First phase of training	13	15	12	-	20	-
Second phase of training	2	-	8	8	33	9
MSc1 – module of fundamental sciences MSc2 – module of fundamental engineering MSc3 – module of mandatory courses MSc4 – module of variable courses						

Block 1 includes disciplinary (MSc1 and MSc2) and interdisciplinary (MSc3 and MSc4) modules, Block 2 provides internship & research (MSc5), and Block 3 includes the final project (thesis), as well as the final examination (MSc6). The program is implemented in two phases. In the first phase (1^{st} year of study), mainly fundamental scientific and fundamental engineering training is provided. In the second phase (2^{nd} year of study), professional training is provided, taking specialization into account. The diagram in the Figure 4 shows the contribution of MSc program modules to LOs focused on F-C-D-I stages of innovative engineering activity.

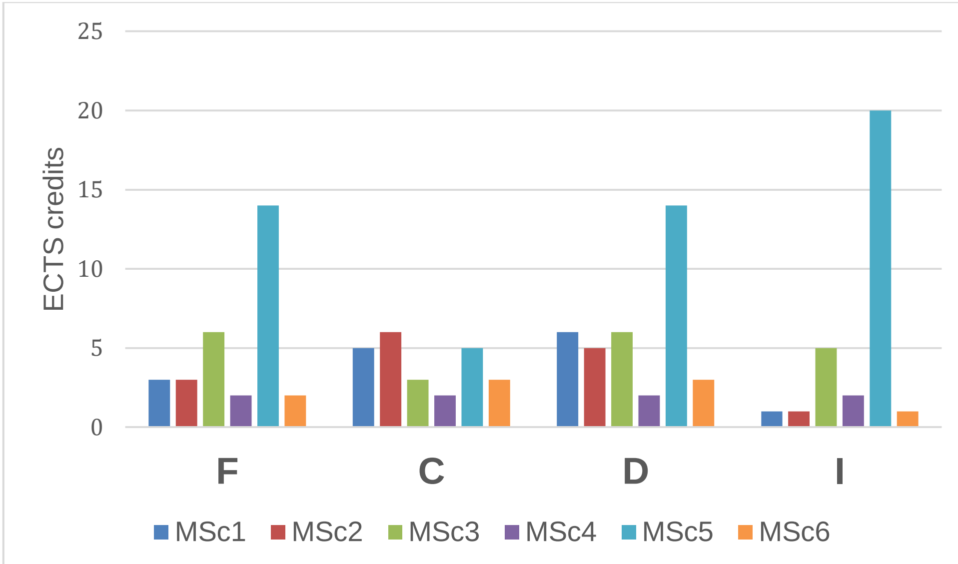

Figure 4. The contribution of MSc program modules to LOs focused on F-C-D-I stages of innovative engineering activity

It follows from the diagram that the greatest contribution to the preparation of graduates to activity at the “Forecast”, “Design” and “Implement” stages is made by module MSc5 (internship & research), followed by module MSc3 (mandatory courses). The contribution of module MSc1 (fundamental science) and module MSc2 (fundamental engineering) is very important to the preparation of graduates to activity at the “Conceive” and “Design” stages. The diagram shows that all modules of MSc program integrated curriculum contribute to the preparation of graduates for innovative engineering activities at all stages.

PHD PROGRAM CURRICULUM DESIGN

The objectives of the PhD program “Technologies of food production from plant raw materials” based on the KubSTU mission and the FFCD Standards are as follows:

1. Graduates should have world-class competences and high civil responsibility necessary for *research* engineering activity in the field of food production from plant raw materials.
2. Graduates should be able to do engineering *research* associated with food production to ensure the technological development of the Kuban Region and Russia.
3. Graduates should be able to conduct engineering activity at the stages of *foreseeing, forecasting, conceiving* and *designing* of food production innovative technologies.
4. When *foreseeing* graduates should be able to carry out scientific foresight of the future of industrial food production and biotechnologies, analyze the society needs, plan research and innovations, implement a technological foresight and analyze "critical" technologies.
5. When *forecasting* graduates should be able to manage knowledge, do research and generate new knowledge, assess needs in knowledge-intensive technology for innovation development in food production.
6. When *conceiving* graduates should be able to create scientific basis for innovative food technology design, develop new technique and technology based on up-to-date knowledge in the area of food production.

7. When *designing* innovative technology of food production, graduates should be able to provide scientific support and expand technological capabilities of production.

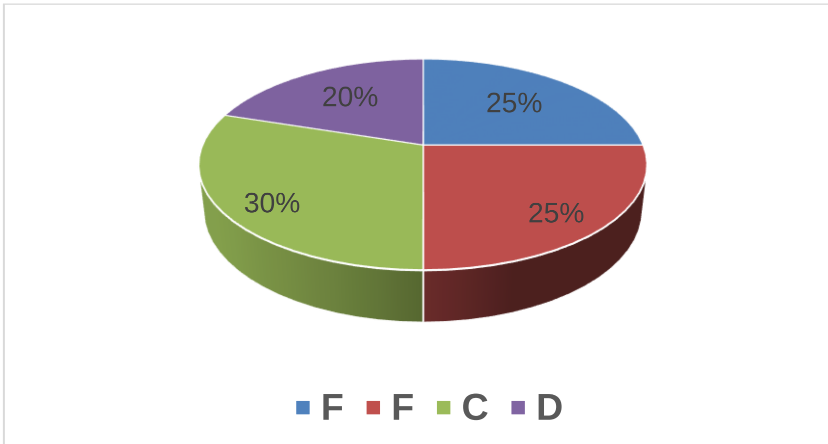

Figure 5. Orientation of PhD program intended LOs to F-F-C-D stages of research engineering activity

The diagram in the Figure 5 illustrates orientation of the 4-year (240 ECTS) PhD program LOs to F-F-C-D stages of research engineering activity. It follows from the diagram that 25% of intended LOs (60 credits) will provide graduate competencies required for activity at the "Foresight" stage, 25% of LOs (60 credits) are focused on the "Forecast" stage, and 20% of intended LOs (48 credits) are focused on the "Design" stage. The area of priority for PhD graduates is "Conceive" stage (30% of LOs or 72 credits).

Table 3 shows the structure of PhD program corresponding to the F-F-C-D orientation (Figure 5) and meeting the FSES 3+ requirements. The program consists of four blocks of curriculum elements. Block 1 includes disciplinary (PhD1 and PhD2) and transdisciplinary (PhD3 and PhD4) modules, Block 2 provides pedagogic internship (PhD5), Block 3 envisages research (PhD6), and Block 4 includes thesis preparation (PhD7). The program is implemented in two phases. In the first phase (1^{st} and 2^{nd} years of study), fundamental sciences and engineering sciences are studied, as well as transdisciplinary courses are mastered. At the same time, PhD students perform a large amount of research. The second phase of the program (3^{rd} and 4^{th} years of study) is mainly focused on research in the area of specialization.

Table 3. The structure of PhD program in ECTS credits

	Block 1				Block 2	Block 3	Block 4
	Disciplinary modules		Transdisciplinary modules		Internship	Research	Thesis
	PhD1	PhD2	PhD3	PhD4	PhD5	PhD6	PhD7
First phase of training	9	7	8	6	-	90	-
Second phase of training	-	-	-	-	2	109	9
PhD1 – module of fundamental sciences PhD2 – module of fundamental engineering sciences PhD3 – module of mandatory transdisciplinary courses PhD4 – module of variable transdisciplinary courses							

The diagram in the Figure 6 shows the contribution of PhD program modules to LOs focused on F-F-C-D stages of research engineering activity. It follows from the diagram that the research (PhD6) is dominant in the preparation of graduates for activity at all stages. However, all modules of the PhD program curriculum contribute to integrated learning experience of PhD students. Modules of fundamental sciences (PhD1) and fundamental engineering sciences (PhD2) consist of the courses providing the necessary theoretical basis for further research in the area of specialization. Modules of mandatory (PhD3) and variable (PhD4) transdisciplinary courses deepen the knowledge necessary to achieve new scientific results in the research area. Pedagogical internship (PhD5) is an indispensable attribute of the PhD program mastering.

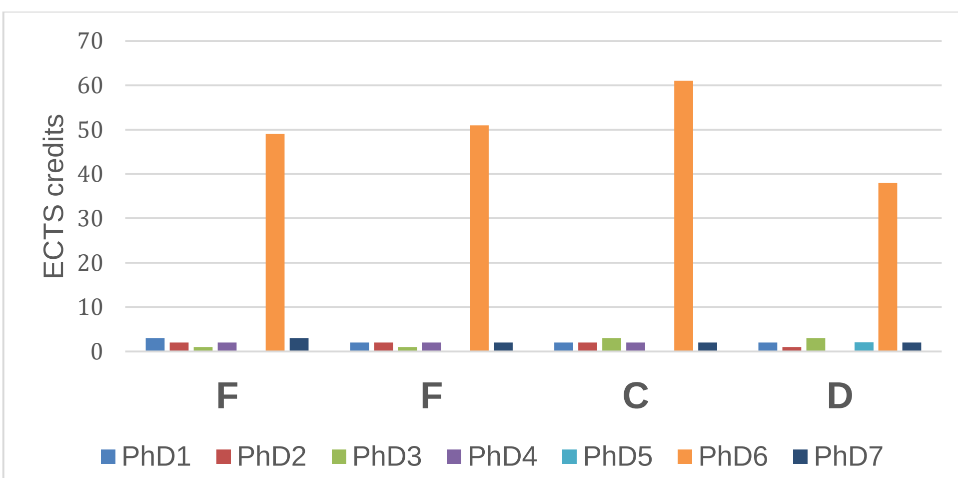

Figure 6. The contribution of PhD program modules to LOs focused on F-F-C-D stages of research engineering activity

CONCLUSION

Modernization of the engineering programs in the field of Food Production Technology simultaneously at 3 cycles of higher education (undergraduate, graduate and postgraduate) based on the CDIO, FCDI and FFCD models is the first experience of practical application of the FCDI Standards and FFCD Standards developed by analogy with CDIO Standards. The programs are being prepared for implementation at Kuban State Technological University in the next academic year. The results of the implementation of the programs redesigned as engineering "triads" will be discussed with the CDIO Worldwide Initiative community in the future. In the case of positive experiment results, the CDIO, FCDI and FFCD models will be used for modernization of the 3 – cycle academic programs in the field of electrical and power engineering, computer engineering, mechanical engineering, etc.

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BIOGRAPHICAL INFORMATION

Alexander Chuchalin, Professor, Kuban State Technological University Rectorate Advisor. His current research focuses on the development and implementation of the CDIO approach adapted to undergraduate, graduate and postgraduate engineering education.

Tatyana Barkhatova**,** Professor, Rector of Kuban State Technological University. Her current research concerns university strategic management and improving the quality of engineering education.

Svetlana Kalmanovich**,** Professor, Head of Department of Fat and Cosmetic Technologies at Kuban State Technological University. Her research focuses on the development of innovative technologies for processing non-traditional types of oil-containing plant raw materials.

Corresponding author

Prof. A. Chuchalin
Kuban State Technological University
2 Moskovskaya St., Krasnodar,
Russian Federation, 350072
chai@kubstu.ru

ENGINEERING EDUCATION RESEARCH

12

EXECUTIVE SUMMARY: A PHD THESIS WITH A CDIO THEME

Kristina Edström

KTH Royal Institute of Technology

ABSTRACT

In December 2017, the author defended the doctoral thesis titled "*Exploring the dual nature of engineering education: Opportunities and challenges in integrating the academic and professional aspects in the curriculum*". In this paper, the thesis is summarised with the interests of the CDIO community in mind, providing guidance for those who might want to read selected parts. In the title, the term *dual nature* suggests that engineering education is both academic, emphasising theory in a range of subjects, and professional, preparing students for engineering practice. Ideally, these aspects are also in a meaningful relationship in the curriculum. However, this duality is also a source of tensions. This is the theme, explored in the context of engineering education development, in particular the CDIO approach. First, micro-cases on programme and course level illustrate how the dual nature ideal is pursued in the *integrated curriculum*. This is followed by two critical accounts, which suggest widening the perspective from curriculum development per se, to the organisational conditions. The first is a historical excursion, comparing the views of Carl Richard Söderberg (1895-1979) with CDIO, showing significant similarities in ideals, arguments, and strategies. The second is an effort to make sense of experiences of unsustainable change, resulting in a model, called "organisational gravity", used to explain the stability of programmes. As an implication, two change strategies are suggested, with different availability, risks, resource demands, and sustainability of results. Finally, the tensions between the academic and professional aspects are located in the university organisation. Refuting a rationalist view, the institutional logics perspective is used to analyse the tensions within engineering education. It is suggested that the logics of the academic profession dominates over the logics of the engineering profession, hence favouring "teaching theory" over "teaching professionals". The integrated curriculum strategy depends on educators' ability to unite theoretical and professional aspects in courses, and on the collegial capacity for coordination.

KEYWORDS

professional education, dual nature, engineering education development, the CDIO Initiative, PBL, engineering education research, Carl Richard Söderberg, organisational gravity, institutional logics, Standards: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12

INTRODUCTION

Title, Theme and Research Questions

The overall theme addressed in this thesis (Edström, 2017a) is the *dual nature* of higher engineering education. By dual nature is implied that engineering education is *simultaneously academic*, emphasising theory in a range of disciplines, *and professional*, preparing students for engineering practice. Hence, the theoretical and professional aspects are not merely two components that need to be balanced in appropriate proportions, but they should also be in meaningful relationships in the curriculum. While the academic-professional duality is an ideal, it is however also a source of tensions. The full title of the thesis is: *Exploring the dual nature of engineering education: Opportunities and challenges in integrating the academic and professional aspects in the curriculum.*

The investigation starts by focusing on the approaches and strategies used to develop engineering education towards the dual nature ideal. The relationship between disciplinary and professional aims is a key issue in many reform initiatives, represented by the CDIO approach as the main case (Crawley, Malmqvist, Östlund, Brodeur, & Edström, 2014). Two critical accounts then suggest widening the perspective from curriculum development per se, to the organisational conditions. The first takes a historic perspective, comparing the past and present discussion. The second considers some of the underlying challenges for this kind of educational change, by discussing experiences of unsuccessful change. Finally, the strategies and challenges will be related to organisational matters.

These interests correspond to the following research questions:

- *What approaches and change strategies can be identified in major engineering education development communities?*
- *How has the tension between the academic and professional aspects played out in the past, and what can be learned from comparing past and present ideals and debates?*
- *What challenges apply to the sustainability of educational development in engineering programmes?*
- *How can we understand those challenges in relation to the university organisation as a context for the change?*

The Context is Development

Not only is educational development the context for this thesis, but it is also taken to imply a critical perspective with focus on tensions and conflicting interests. The term *development* already implies a normative stance, as it usually refers to deliberate change to the better. Development is therefore like a vector; it has a direction as a part of its definition. The direction can be seen as an agenda, somebody's agenda, which means that also agency and interests are implied. In the discussion about what development is desirable in engineering education, there are many different positions possible, but it is a normative, ideological or political debate, meaning that there is no objective or neutral position available. Barnett (1992, p. 6) puts it bluntly:

> "The debate over quality in higher education should be seen for what it is: a power struggle where the use of terms reflects a jockeying for position in the attempt to impose own definitions of [the aims of] higher education."

The thesis also draws on the author's personal experiences in engineering education development, within the CDIO Initiative and other contexts. Maintaining the credibility of this research is not about pretending to be neutral and objective, since such a position might not even exist, but about being aware of, and openly disclose, the personal perspective. For instance, depicting the dual nature of engineering education as an ideal and making it sound natural and reasonable, as was just done above, is to take a normative stance. While most people would agree, there *are* also other positions possible. The fact that accreditations and qualification frameworks mandate the ideal does not make it neutral; it is still a value statement. Hopefully, given the full disclosure, the insider perspective might also bring strengths, because "understanding change is just as much a matter of 'doing' reform as it is studying it" (Fullan, 1999).

EFFORTS TO INTEGRATE ACADEMIC AND PROFESSIONAL AIMS

Chapter 2 of the thesis can be read as an introduction to CDIO. It explores the CDIO approach as a major attempt to develop curricula according to the dual nature ideal.

The Integrated Curriculum

The starting point of the CDIO Initiative was the recognition that engineering education had become increasingly distanced from engineering practice, as engineering science had replaced engineering practice as the dominant culture among faculty in the past few decades (Crawley, 2001). It is also a critique of "poorly designed curricula, at worst consisting of disciplinary courses disconnected from each other, and as a whole, loosely coupled to espoused programme goals, professional practice, and student motivation" (Edström & Kolmos, 2014, p. 549). The aim is to develop programs for better educating students in developing and deploying technology (or, unpacking the CDIO acronym, conceiving, designing, implementing, and operating technical products, processes and systems). However, while advocating enhancement of professional competence, the first aim of CDIO implementation is still a deeper *working* understanding of disciplinary fundamentals, since this also constitutes a critical preparation for practice. The strategy formulated by the CDIO community is to integrate disciplinary theory and (other) professional aims through curriculum development, on the programme level, on the course level, and in faculty development (Crawley et al., 2014). The objective is to achieve an *integrated curriculum*.

Micro Case: The Mechanical Engineering programme at Chalmers

This case illustrates the programme level focus in CDIO (Standards 1, 2, 3, and 12). At Chalmers, the CDIO methodology is used to keep the programmes unified, although they consist of courses from several departments and disciplines. The programmes commission courses from the departments. Every year, the programme leaders review the course evaluations, and negotiate next year's course offering in a dialogue with the vice head of the delivering department. While this is a collegial dialogue, the programme controls the budget, approves the course syllabus documents, and is the recipient of course evaluations. The Mechanical Engineering programme has created conditions for systematically leading, planning and developing the programme, and for *constantly setting new goals* (Malmqvist, Bankel, Enelund, Gustafsson, & Knutson Wedel, 2010). Skills such as communication, teamwork, and ethics are integrated in several courses with progression throughout the years. They have also repeatedly demonstrated how the curriculum can be further developed through a relatively agile process.

One particularly interesting development is the integration of computational mathematics, aiming to modernize the mathematical content while also strengthening the connection between engineering and mathematics. The rationale was that students need to learn to solve more general, real-world problems, and spend less time "*solving oversimplified problems that can be expressed analytically and with solutions that are already known in advance*" (Enelund, Larsson, & Malmqvist, 2011). A guiding principle was that students should work on the complete problem, from identification and formulation, modelling, simulation, visualization, evaluation. Instead of framing this as a task for mathematics teachers to solve within the mathematics courses, the programme approach was applied, and creating connections to mathematics in engineering subjects was at least as important as making connections to engineering in mathematics. Interventions include new math courses where computational tools are used, new teaching materials, integrating relevant mathematics topics in fundamental engineering courses (e.g. mechanics and control theory), as well as cross-cutting exercises, assignments and team projects shared between the engineering courses and mathematics courses. Similarly, the integration of sustainable development demonstrates how the programme approach enables systematic integration of important cross-cutting topics in several courses, linked to overall programme learning outcomes and ensuring progression (Enelund, Knutson Wedel, Lundqvist, & Malmqvist, 2013).

Course level development

In Mechanical Engineering, the programme-level planning went hand in hand with programme-driven course development, to address the learning objectives that were assigned to courses. Standard 7, 8 and 11 constitute a course design model corresponding to constructive alignment: the learning objectives, learning activities, and assessment should be aligned (Biggs & Tang, 2011). Hence, the integration between disciplinary knowledge and professional skills should apply in all these components.

What sets CDIO apart from other concepts for engineering education development is the recognition of contributions of both discipline-led and problem/project-led approaches. Table 1 shows some arguments for why both logics are necessary, and how they can form a productive relationship.

Table 1. The need for both discipline-led and problem/practice-led learning.
Adapted from Edström and Kolmos (2014).

Discipline-led learning is necessary for:	**Problem/practice-led learning is necessary for:**
▪ Creating well-structured knowledge bases ▪ Understanding the relations between evidence/theory, and model/reality ▪ Methods to further the knowledge frontier **…while also connecting with problems and practice:** ▪ Deep working understanding (ability to apply) ▪ Seeing the knowledge through the lens of problems ▪ Interconnecting the disciplines ▪ Integrating skills, e.g. communication and collaboration	▪ Integration and application, synthesis ▪ Open-ended problems, with ambiguity, trade-offs ▪ Problems in context, including human, societal, ethical, economical, legal, etc. aspects ▪ Practicing professional work modes ▪ Design – in Theodore von Kármán's words: "Scientists discover the world that exists; engineers create the world that never was" (NSF, 2013) **…while also connecting with disciplinary knowledge:** ▪ Discovering how disciplinary knowledge is used ▪ Reinforcing disciplinary understanding ▪ Creating a motivational context

Together with subject courses, project-based learning is an essential component in the CDIO curriculum (Edström & Kolmos, 2014). In particular, Standard 5 implies a sequence of projects in which the students work on real problems, learning through the development and deployment of products, processes or systems, in working modes resembling engineering practice. The hands-on engineering should start early (Standard 4) and progress through the programme. This is a reaction to curricula where the first years are filled with basic theoretical subjects, and students risk losing sight of why they wanted to become engineers in the first place (see for instance Holmegaard, Madsen, & Ulriksen, 2016; Holmegaard, Ulriksen, & Madsen, 2010).

On the course level, two cases, one a subject course and the other a design project course, are presented to illustrate CDIO educational development.

Micro Case: Improving student learning in a subject course

This case (Edström & Hellström, forthcoming) demonstrates how a modest and cost-effective intervention can improve the contribution of subject courses, improving students' understanding of disciplinary theory *while also allowing them to practice communication skills* (Standard 7). This shows that the synergy between disciplinary and professional aims can be realised on the course level. The intervention, called student-led exercises, aims to improve learning in problem-solving sessions. Instead of the teacher demonstrating calculations on the board (which is considered "normal" at KTH), students are randomly selected to present their solutions, prepared in advance. This teaching method was implemented in two sites, at KTH in a *Semiconductor Devices* course, and at the University of Oslo in the very large first-semester *Introduction to Chemistry*. The implementations provided different insights. Based on quantitative data in the form of course results, qualitative data in the form of student interviews, and teacher reflections over the experiences, the results at KTH indicated improved understanding and motivation, while the most consequential result in Oslo was a significant decrease in dropouts.

Micro Case: Improving student learning in a project course

This case describes a master level design project course at the Vehicle Engineering department at KTH. Student groups build things like a solar powered aircraft, an autonomous underwater glider, or an electric single-hydrofoil vehicle for play (for video clips, see Kuttenkeuler, 2017). The reflections and experiences are reported in conferences (Edström, El Gaidi, Hallström, & Kuttenkeuler, 2005; Edström, Hallström, & Kuttenkeuler, 2011; Hallström, Kuttenkeuler, & Edström, 2007) and a book chapter (Hallström, Kuttenkeuler, Niewoehner, & Young, 2014). The case demonstrates a learning-centred design of teaching and assessment. In short, the purpose is not that the students should build things; it is that they should *learn* from building things. It shows how this learning activity, including individual grading of student learning, can be sustainable from a teaching perspective. This makes it a proof-of-concept for project-based learning which is not necessarily very expensive or requires high teaching effort.

The course design and teaching philosophy are guided by some key principles. For one thing, *teachers do not stand between the students and the problems*. In other words, students are directly exposed to real problems in the project work. Another principle is that the *students own the project*. The teachers' role is to coach the engineering process, but not to drive it, and *never suggest solutions*. Hence, students are not protected from mistakes, contradictions or confusion, and the project results will reflect the proficiency of the students, not of the teachers, because *learning is prioritised* over the product performance. A related principle is that *the project sets the logic*. This means that teachers refrain from unnecessarily making decisions. For instance, when the project commissions an investigation by a sub-team, their report should contain precisely the information needed to make the subsequent decision. Hence, details like the page count or the deadline, follow as *consequences of its function*, not from what the teacher wants. When students let go of the teacher orientation and start becoming project-oriented, their work becomes more meaningful, and easier. When teachers refrain from managing (and micro managing) the project, it also makes the course more sustainable in terms of teacher time.

Faculty Development

The cases clearly indicate new demands on the teacher competence, regarding what to teach (Standard 9), and how to design the learning activities and assessment (Standard 10). The development of the integrated curriculum is enabled and limited by faculty teaching competence and faculty engineering competence. On the course level, the integration strategy works, but it *depends on the individual faculty* and their willingness and ability to unite the theoretical and the professional. It works to the extent that they are prepared to attend also to professionally relevant aspects that are not necessarily part of the teaching traditions of the subject. On the programme level, CDIO devises a process for establishing structures to hold the curriculum together, making the programme a joint collegial project, where every course has an explicit function towards the programme goals. The integrated curriculum works, but it *depends on the faculty capacity for coordination.* One particular challenge with recommending faculty development as part of a programme-centred development concept is that although it is an important condition for success, perhaps the most critical, it is a domain in which the programme may lack influence. This is also where least progress is reported by CDIO implementers (Malmqvist, Hugo, & Kjellberg, 2015).

ENGAGING WITH THE PAST

Chapter 3 of the thesis (see also Edström, 2018) makes a historical excursion to problematize the theme.

Perhaps a historical innocence makes it easier to take on this kind of work with optimism, but to be self-critical: we sometimes act as if the problems we work on were discovered in our time, and we devise solutions as if nobody has suggested or tried them before. Comparing past and present discussions will show not only how the issue has a long history, but also that many of the arguments and proposed strategies for addressing it remain very similar across time.

Seely (2005) pointed out that when we consider educational reform it is useful to see what has led to the situation that we have now, and to recognise patterns in the history of reform attempts. He uses *the swinging pendulum* as a metaphor to describe the turn from practice to science, when engineering education in the United States was transformed due to a dramatic increase in research that started during World War II. The engineering science endeavour was a strategy for status and a strategy for institutional growth. An “avalanche” of government research funding changed the character of faculty, and the dominant culture went from engineering practice to engineering science, leading to increasingly theoretical curricula. While science and theory were originally intended to improve professional preparation, it came instead to dominate the education. Many observers, including prominent proponents of the science-based curriculum, felt that the baby had been thrown out with the bath water.

This was the background against which the life and work of Carl Richard Söderberg (1895-1979) is traced, focusing on his views of engineering education. He emigrated from Sweden to the US for an illustrious industrial career. In 1938, he became a professor at MIT, and eventually ending his career as Dean of Engineering. While he was a proponent for a more science-based curriculum, his rationale was related to solving real professional problems, and he would come to criticise the distancing of engineering education from engineering practice. Comparing Söderberg’s views to CDIO shows the persistence of the issue, as many of Söderberg’s ideals, arguments, and proposed strategies are fully recognisable in the current discussion. Further, Söderberg and CDIO share the ideal of mutually supporting professional and disciplinary preparation, implying that the tension should not be a zero-sum game. The paths to this ideal were different, however, as Söderberg wanted to integrate theoretical aspects to improve an overly practical education, while CDIO is about improving an overly theoretical education by integrating also other necessary professional aspects. Söderberg and CDIO both recognise the dual nature of engineering education, and refuse to single out one side over the other. When Söderberg advocated a more theoretical approach, it was to *strengthen* professional practice. Likewise, when CDIO advocates professional competence, the deeper working understanding of disciplinary fundamentals constitutes a critical preparation for practice.

The common ideal identified here is to make the professional and disciplinary preparation mutually supporting. The conclusion is that engineering education would benefit from ending the trench wars over “how much” should be theoretical or practice-oriented, and make more efforts to strengthen the meaningful *relationship* between these aspects in the curriculum. This shows that Seely’s swinging pendulum metaphor fails to challenge the misconception that engineering education must necessarily lean *either* to the academic *or* to the professional side. One conclusion is to let go of the swinging pendulum metaphor. Instead of seeking balance and compromise, as the pendulum imagery would suggest, we should seek syntheses and synergies.

It makes a point to focus on Söderberg as a person, because he so clearly combined the practical and theoretical interests, himself embodying the dual nature of engineering. This may suggest that to achieve the integrated curriculum, enough people in the faculty must be able to simultaneously defend both academic and professional values. The binary view, associated with the pendulum image and the trench wars over the curriculum, may be unavoidable if too many people favour one side with little consideration for the other. In fact, engineering faculty need competence in three areas: theoretical-scientific expertise, professional competence, and teaching competence. If these demands seem daunting, we can look around our faculty and say: "*We have such people; we can have more*" (MIT, 1949, p. 93).

MAKING SENSE OF UNSUSTAINABLE CHANGE

Coming back much nearer the present time, chapter 4 in the thesis provides another critical perspective, by considering experiences of unsustainable change.

In 2011, the author had been discussing experiences of engineering education development with educators, programme managers, deans, and educational developers for over a decade. A pattern began to emerge when some colleagues confided that even in projects that were considered highly successful, the results were smaller than intended, and further, that change was not sustainable, in that engineering programmes tended to revert "back to normal". They reported that they felt a need to constantly work hard just to sustain the change. Otherwise, when their attention turned to other matters, the new practices would wither away and the programme revert. The poor sustainability of change had evidently come as a surprise. There was a remarkably common theme in their stories, but what was it and how could it be understood? It also felt novel, as it was not part of the normal discourse about change in the educational development community. Several new questions emerged: What makes programmes revert? What do they revert to? Is there a particular ground state for a programme? If so, what defines or shapes it, what is it that makes it "normal"? Why is this more stable than other states?

Organisational gravity

The lack of concepts to describe the phenomenon indicated a need for theorizing. The result was a model connecting the educational programme with the organisational characteristics of the organisation:

> Organisational gravity is a force acting on education programmes, causing them to reflect the inherent characteristics of the organisation providing it. The most stable state (lowest energy state) for a programme is thus to reflect the institution. This is the ground state. Every other state requires that some kind of energy is introduced into the system to counteract the gravity and 'lift' the programme to an alternative, more desired, state. Such energy can be applied in many different forms, for instance through money, leadership, attention, and other resources, in projects and interventions. But since the organisational gravity keeps exerting its force on the programme, we must continuously add resources to keep it from reverting to the ground state (Edström, 2011).

The model postulates that the ground state for educational programmes is to simply reflect the organisation. It should then be possible to analyse what type of educational development could be harder to achieve and sustain, and what types should be easier. For instance, the model can explain why engineering curricula often consist of subject courses that reflect the organisational boundaries of the university: Even when cross-disciplinary learning activities are considered desirable for the education, they seem harder to form and sustain across organisational boundaries. Many practical issues need to be resolved, with different cost centres and administrative classifications. Crosscutting collaboration involves extra work to establish and maintain, and they are vulnerable since they often rely more on personal connections. It is consistent with the model that programmes consist mainly of courses corresponding to the administrative territories of the organisational chart. The organizational boundaries, often the same as the disciplinary boundaries, tend to be reflected in the courses of the programme.

The model can also explain why it is hard to integrate learning outcomes related to professional practice: To provide professional preparation, the university needs strengths related to integration and application of knowledge, to ‘real’ engineering problems, which require integration, interpretation of the context, and judgement and creativity in conceiving and implementing solutions. But when hiring and promoting faculty, disciplinary research merits are more valued, often associated with reduction, analysis, and increasing specialisation. Hence, the faculty, collectively, have relatively little professional engineering experience and researchers may see problems that do not map to the disciplines as outside their perceived responsibility. This is why it takes special effort in a discipline-based organisation to create programmes that address learning outcomes related to professional engineering practice. It is consistent with the model that some of the most desired learning outcomes are difficult to address in the education, because their representation in the organisation is too weak. To conclude, *values that are not sufficiently represented in the setup of the organisation are harder to implement sustainably in programmes*. Unfortunately, this applies to some of the most important learning outcomes in engineering education.

The organisational gravity model describes how the characteristics of the organisation shape the education programme as an image of the organisation, unless resources are constantly applied to keep it in a more desirable state. Organisational characteristics are interpreted in a very wide sense – a simple working definition would be “*how things work around here*” (Edström, 2011). Different factors interplay and influence each other, and in particular, some factors can enable or limit change in others. Internal factors are influenced by the external, and soft and hard factors shape each other – ”*the symbolic takes part in creating the real*” (Dahler-Larsen, 1998, p. 54).

Two change strategies

Derived directly from the model is the idea that there are, in principle, two kinds of change strategies available for developing educational programmes: the force strategy and the system strategy. The *force strategy* means *adding some kind of extra energy* to move the educational programme to a more desirable state, away from just reflecting the organisation. The extra energy, or force, can take many forms: as funding, leadership, attention, alliances, evaluations, lobbying, personal energy, etc. This strategy is available to all actors; everyone can apply their own force. The disadvantage is that it must be *continuously applied*, to prevent the programme from reverting. It is therefore potentially not very resource-efficient. This is not to say that the force strategy does not work, but it works like agriculture: new seeds must be sown every year. This understanding can inform expectations regarding results and their sustainability, and remind us to plan for a continuous supply of resources. The drawback is that the force strategy risks straining people, partly because of the high effort it takes to achieve results, and to sustain them, and partly because their efforts are likely under-rewarded, since they do such work that – by definition – does not build a career in the organisation.

The *system strategy* means *changing the characteristics of the organisation* to enable a more desired stable state for the education. This is not only about changing *what we do* in the education, but also *who we are* as an organisation, because the values needed for the educational mission must be present. In other words: *to sustainably change the education it is not sufficient to change the education*. To accommodate professional education, values related to integration and application (cf. Boyer, 1990) must also be sufficiently represented in the organisation. The system strategy is less available, because fewer actors have access to the most important shaping mechanisms, such as career systems and funding systems. These systems also change rather seldom. The advantage is that even small changes, for instance in the requirements for appointment and promotion, can have considerable and lasting effects. The ideal is to align the university, as a system, with both its research and educational missions. Then, in theory, organisational gravity could become a positive force, pulling the curriculum in the right direction.

To summarise, both strategies have their uses, as they come with different strengths, weaknesses, availability, limitations, risks, and implications for resource-effectiveness and sustainability of results. Even if the force strategy seems unwise at first sight, the Sisyphean labour may be useful and justified. It is understandable if university leaders hesitate to use the system strategy. If it is mainly research-related indicators that will determine the long-term survival and prosperity of the institution, there are risks associated with creating an organisation that can accommodate good research *and* good education.

HOW THINGS WORK AROUND HERE – THE ORGANISATIONAL PERSPECTIVE

The historical turn and the organisational gravity model have in different ways problematized engineering education development. Chapter 5 in the thesis follows up on the suspicions that were generated, that the crux of the matter lies in the relation between the nature of change and the setup of the organisation.

The University is Not a Machine

Our mental concepts and theories can function as lenses for perceiving and interpreting things that may otherwise have gone unnoticed, or they may limit our view, because by highlighting some aspects they will also relegate others to the background. A technical university is dominated by engineers, who, according to Picon (2004, p. 429), have a strong tendency for functionalist rationality. A suitable metaphor for the organisation would then be a machine, suggesting an organisation optimised for effective operation, structured along the organisational chart, and designed to coordinate its activities "*in a routinized, efficient, reliable and predictable way*" (Morgan, 2006, p. 13). This view is not necessarily wrong, but it lacks explanatory power for many aspects of university life. We note for instance that the experiences of unsustainable change (described above) came as a surprise to the informants. In particular, the machine metaphor is unproductive when it comes to formulating models for change. In fact, the only change strategy that can be derived from this organisational understanding is that change should be mandated from the top and aimed at improving the outputs. But the experiences above showed that top-level decisions, access to resources, and the best intentions with respect to the outcomes of education were not sufficient conditions for sustainable change. Thus, a top-down and function-oriented model of the organisation is not sufficient to inform development, or make sense of experiences. In the following, an alternative framework will be assembled, more appropriate for analysing the university as an organisation and for assessing the implications for educational development.

The Institutional Logics Perspective

The following draws on theory which describes organisations as embedded in and infused by *institutional logics* (Friedland & Alford, 1991; Thornton & Ocasio, 2008; Thornton, Ocasio, & Lounsbury, 2012). Institutional logics can be succinctly expressed as "*the way a particular social world works"* (Jackall, cited by Thornton et al., 2012, p. 46), which seems similar to the working definition suggested above: "*how things work around here*" (Edström, 2011). If the machine metaphor focuses on formal and visible structures, resources, activities and outputs, the institutional logics perspective *also* emphasises the subtler roles played by norms, values, beliefs, assumptions, culture, and identities.

On the highest level, Thornton et al. (2012, p. 73) list seven ideal types of institutional logics in society: *state, market, community, profession, corporation, family, and religion*, each with their own set of norms, and sources of legitimacy and authority. On the next level is the institutional field, where combinations of the societal logics are at play. For instance, in the higher education sector, some practices are shaped by professional logics (e.g. peer review), while other aspects are shaped by market logics (e.g. technology transfer) or state logics (e.g. degree frameworks). In a complex institutional environment with incoherent demands, there may be tensions between different logics, leading also to tensions between the logics embedded within any particular university.

Practices and identities

Practices are intimately connected to the institutional logics of the organisation. There is "*a fundamental duality between logics and practice, where constellations of relatively stable practices provide core manifestations of institutional logics*" (Thornton et al., 2012). Practices may reflect the institutional logics differently, as they align with different parts of the institutional environment, for instance uncoordinated constituents. This can create tensions *between practices*, *within practices*, and between institutional rules and the *effectiveness* of the practice. Further, practices may be conceptualised as interdependent, so that changes in one practice may have ramifications for other practices in the organisation (p. 141). Here, the interdependence of education and research will be in focus.

There is also a close relationship between practices and *identities*; we can say that they are co-produced. The availability of standardised social identities in higher education also has great importance for identity. The classifications of individuals are important, and in fact, education can be seen as a process where students pass through a series of stages, every transition carefully controlled, e.g. admission, examination, degrees. The classification of academics is no less important; just think of disciplines, titles, appointments and promotions. The tight link between identity and practice is also evident when we consider how *status* is attached to both. Complex institutional environments can generate patterns of differentiated status between organisations, and between different practices and groups within the organisations. Status also affects the relationships with the resource environment and high-status actors have priority access to the most valuable resources.

Identity and Status in Curriculum Change

Since engineering education development is precisely an attempt to change one of the practices of the university, the theory now becomes very relevant. It connects the practices inside the organisation, *what we do,* and the identities, *how we see ourselves,* to institutional logics. It is a key concern how the "old" or "new" curriculum models relate to the institutional logics, to other practices – to research in particular – and to identities in the organisation. If we consider the curriculum also as an expression of educators' identity, it is clear that changes can be seen as more or less valuable and meaningful, or improper and threatening.

Status plays an important role. Change may be strongly resisted if it is perceived as a threat to the status of organisations, groups, or individuals. Status can however also further change, since those that are perceived as successful and legitimate are role models likely to be imitated by peers – and this applies to organisations (DiMaggio & Powell, 1983) as well as to individuals and groups within the organisation (Deephouse & Suchman, 2008, p. 61).

In her influential study of academic identities, Henkel concluded that the *discipline* and *academic freedom* were the two things that mattered most, "in many cases the sources of meaning and self-esteem, as well as being what was most valued" (Henkel, 2005, p. 166). If the curriculum is an expression of faculty identity, any changes in practices and structures will obviously be strongly resisted if they are perceived to threaten these values. Considering the main strategy in CDIO programme development, two problematic tensions can be identified. First, the strategy to integrate professional aspects in courses differs from the traditions of the discipline. Then, the need for coordination across the curriculum can be seen to limit academic freedom. A reform that can draw on core values in faculty identities may instead have an advantage.

DISCUSSION

Chapter 6 of the thesis considers the academic-professional duality and its tensions, in the light of the theoretical framework from the previous chapter.

Analysing the Dual Nature Ideal

We saw that institutional logics – patterns of material practices, assumptions, values, beliefs, and rules – are embedded in the practices and identities within the university. In complex institutional environments, the logics embedded within a particular practice can contain contradictions. The proposition here is that the engineering curriculum expresses the institutional logics of two professions: *the logics of the engineering profession* that we educate for, and the *logics of the academic profession* of the educators. These logics come with slightly different assumptions, beliefs and values regarding the educational mission and the role of the educators. The logic of the engineering profession reasonably assumes that the educational mission is about teaching the next generation of engineering professionals. In the logic of the academic profession it could instead be reasonable to see the teaching mission as conveying the theory of their discipline. See Figure 1.

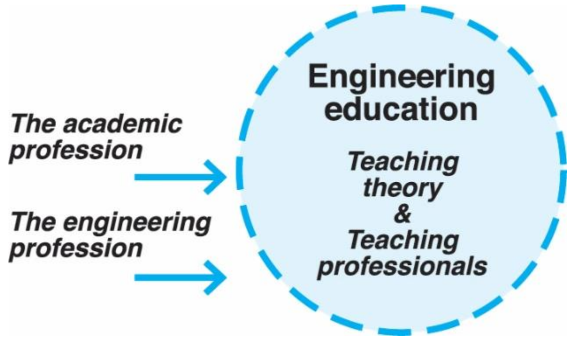

Figure 1. Engineering education, a practice expressing two professional logics.

Some aspects in which the institutional logics of the two professions differ are elaborated in Table 2. The analytic scheme is not meant to set these two sides of education against each other. For instance, when we consider what knowledge is seen as relevant (see Table 2, row 3) there is no doubt that disciplinary fundamentals are useful for engineering practice. But when they are taught with the approach of the academic profession, the main emphasis is often on deriving or proving the theory, most often going through the subjects one at a time. In contrast, when disciplinary fundamentals are taught with the approach of the engineering profession, emphasis is on achieving a working understanding, i.e. the competence in using theory from many disciplines in the context of real problems. The point here is precisely that *both sides are necessary*, and according to the dual nature ideal, they should also be in a *meaningful relationship*.

As another example, we consider what problems and questions are seen as interesting (see Table 2, row 4). We want students to be *problem-oriented*, considering how to solve consequential social and economic problems in society, but we also want them to be *discipline-oriented*, to think in terms of new technology looking for applications – and they should ideally be able to combine these two perspectives.

Table 2. Analysis of the institutional logics of the engineering profession and the academic profession, respectively.

Institutional logics	**The engineering profession that we educate for**	**The academic profession of the educators**
The role of the educator	Teaching future engineers	Teaching theory
Relevant knowledge	Knowledge useful for engineering practice	The disciplinary fundamentals
Interesting problems and questions	Real problems, consequential issues in industry and society	Pure problems, close to the disciplinary frontier
Students are prepared for	Engineering practice – through deep working knowledge and professional competences	Engineering practice – through theoretical knowledge Research education – disciplinary depth

The ideal to combine these perspectives in education does not prevent manifestations of contradictions and tensions between the logics. For instance, the cases of unsuccessful change suggested that some of the values necessary for engineering education are weakly represented in the organisation. In the language of institutional logics: when the professional logics are weakly represented among the faculty, it is more difficult to satisfy the related aspects in the curriculum. Similarly, in an organisation where the academic profession is weakly represented, it would be difficult to satisfy the aims in the right-hand column of Table 2. Simply put, the capacity to teach disciplinary theory is strengthened by the academic logics, while the professional logics create capacity for addressing also the other necessary aims of the curriculum.

Competing logics in research

The other practice in the technical university, research, can be characterised by a similar tension within its institutional logics, where two beliefs about the aims of research exist simultaneously: one that research aims to further knowledge for its own sake, and one that research is guided by a consideration for usefulness in society.

The first belief can be expressed as *the university as academia*. Knowledge "for its own sake" quickly translates to the same thing as furthering a discipline, because the academic career depends on peer recognition, making disciplines the site that controls the necessary resources for survival. Peer approval is a *sine qua non,* since those whose work does not pass this disciplinary quality control will be marginalised by the lack of resources. Quite aptly, Gibbons et al. (1994) called disciplines the "*homes to which scientists must return for recognition or rewards*". Academic capital comes in hard currencies such as being accepted for publication, passing a thesis defense, being appointed and promoted, receiving grants and prizes, and being selected for commissions. Many of academic decisions concern classifications of individuals, which is a particularly important component of identity, and in the career system, research merits dominate every step. All this helps explain the strong socialisation of faculty into the discipline-based identity and beliefs.

The second belief, *the university as public service* implies that research is guided by *consideration for use*. The challenge is how to evaluate the usefulness dimension of the work, and who should be seen as the legitimate judge. It is quite suggestive that even funding for highly applied research is often dispensed based on academic peer review. See Figure 2.

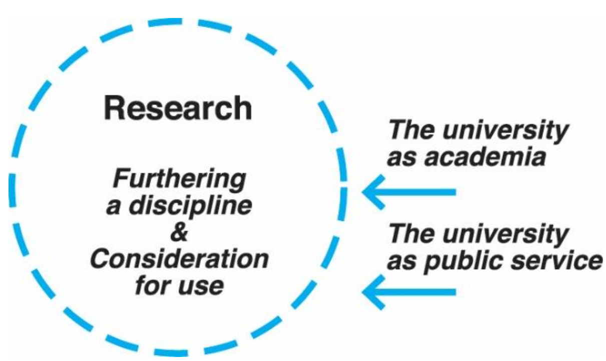

Figure 2. Two aims of research, with corresponding beliefs.

Given that the resources under academic control are so vital, the proposition here is that "university as academia" has stronger support in the institutional logics than does the "university as public service". While the former is highly consistent with the logics of the academic profession, the latter has strong similarities with the logics of the engineering profession, for instance the values attached to integration, application, the interest in real problems that are consequential in society and industry, and their real solutions. These two beliefs are not mutually exclusive, as research can simultaneously be directed toward applied goals and lead to significant new understandings (Brooks, 1967; Edström, 2017b; Stokes, 1997). There is, however, still a core distinction, similar to the description by Williams (2002): "*In science, the fundamental unit of accomplishment remains the discovery; in engineering, the fundamental unit of accomplishment is problem-solving*" (p. 44). The conclusion here is that in the research practice, *the logics of the academic profession enjoy the strongest support in the institutional environment*, both normatively and materially.

Interplay between education and research

Education and research have so far been discussed separately, focusing on some tensions *within* each practice due to inconsistent demands in the embedded logics. What remains is to consider their *interdependence.* The two figures can be merged, see figure 3. The focus here are the different conditions for the practices, and how research influences engineering education. The theoretical framework can tell us that, due to inconsistent institutional demands, we can expect patterns of *differentiated status* between these practices and between groups within the organisations. We can further expect tensions *between* practices, and between institutional rules and the *effectiveness* of the practice.

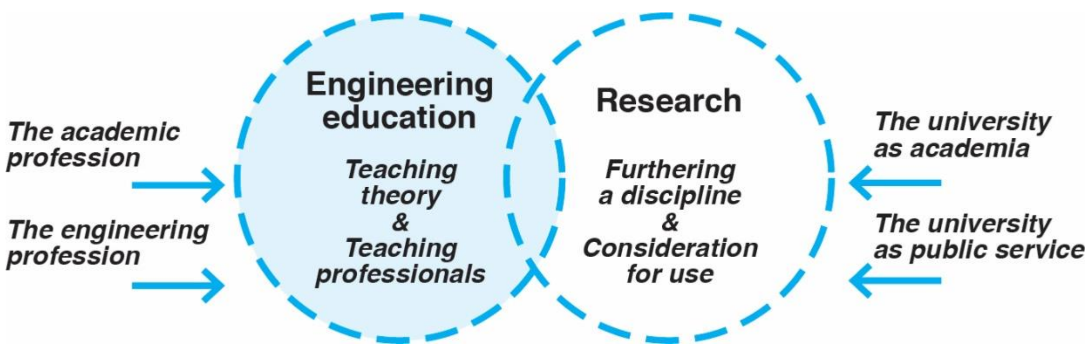

Figure 3. Competing institutional logics in education and research.

Seeing the university from the outside, engineering education and research both enjoy high status. However, within the university, while there is certainly status in excellent teaching, the status of research is generally even higher. We also remember the imperatives created by the "university as academia" described above. While teaching merits feature increasingly in the hiring and promotion criteria, from a career point of view it seems sufficient to be above a threshold level (Graham, 2015). Another reason is the different resource environments. Education funding is distributed internally, often based on quantitative factors without reward for quality. Research funding varies considerably between research fields, in terms of availability, and whether the funds afford freedom, or come with strings attached. But in contrast to education, research funding is often sought externally and in competition based on peer review; the rewards for excellence are considerable in terms of resources and prestige. In short, the socialisation and reproduction of the faculty, and the incentives of the resource environment result in a dominance of research. In conclusion, *research has stronger institutional support than education, both normatively and materially*. This affects the conditions for education generally, including related matters such as the attention paid to teaching competence, teaching quality, and educational development.

The focus here is the dual nature of engineering education, which was conceptualised above as competing logics within the education practice: teaching theory and teaching professionals. But because of the crucial role played by research in shaping the faculty, the suggestion here is that the institutional logics of research, being the dominant practice, strongly influences the institutional logics of the education, because it is shaping the faculty. Hence, *the more the research practice is dominated by the academic logics*, over the consideration for use*, the more it will tilt the balance also in education, in favour of teaching theory*, rather than teaching professionals. If the balance is heavily tilted, it will also be difficult to achieve the ideal of a productive relationship between the academic and professional aims.

In the picture painted here, research has the primary position in the university organisation, positioning education as a secondary practice. The institutional logics of the academic profession have the upper hand not only in research, where disciplinary interests take priority over considerations for use, but also in education, where teaching theory takes priority over the other aspects of professional preparation. No wonder then, if it is difficult to make certain kinds of educational changes sustainable, when the primary practice exerts its constant influence. This happens through the faculty, whose academic identity is stronger than their engineering identity, because research is the birthplace of new faculty, and it also holds the keys to continued survival and success. While the organisation naturally needs to spend considerable attention to its own academic reproduction processes, one may wonder if it has not taken a life of its own, to the point where it fully takes precedence over the educational mission of the university.

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BIOGRAPHICAL INFORMATION

Kristina Edström is an Associate Professor in *Engineering Education Development* at KTH Royal Institute of Technology. Since 1997 she leads and participates in educational development activities at KTH, in Sweden and internationally. She serves on the CDIO Council and is Editor-in-Chief of the *European Journal of Engineering Education*. Kristina has a M.Sc. in Engineering from Chalmers, and a PhD in Technology and Learning from KTH. Her research takes a critical perspective on the why, what and how of engineering education development.

Corresponding author

Kristina Edström
KTH Royal Institute of Technology
SE-11431 Stockholm, Sweden
+4670-699 1420
kristina@kth.se

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A TYPOLOGY OF ENGINEERING DESIGNS IN PROBLEM-BASED PROJECTS

Samuel Brüning Larsen, Per Valentin Bigum

Center for Bachelor of Engineering Studies, Technical University of Denmark

ABSTRACT

The *problem-based project* is a widely applied method for creating learning experiences that closely resemble engineering practice. Problem-based projects support active learning, experience with design and implementation, and integrated learning experiences. These three learning principles are all key standards in CDIO. In problem-based projects, teams of engineering students develop solutions to problems (often across disciplines and in cooperation with an industrial partner, e.g. a manufacturer, a public utility, or a software developer). A good solution meets design requirements and solves the project's problem. However, beyond these two characteristics, the nature of (good) engineering solutions is under-explored. The purpose of this study is to contribute to the understanding of the nature of engineering solutions in problem-based projects across engineering disciplines. The study's findings include a set of general characteristics of great engineering solutions and a typology of three solution archetypes. The study labels these archetypes as 1) the adapted solution, 2) the "either/or"-solution, and 3) the multiple-elements solution. For each archetype, the paper specifies the corresponding class of problems that the archetype can logically address. In addition, the paper delineates (1) how each archetype relates to a project's analysis and (2) how each archetype is evaluated, implemented and operated. The typology aids both students and project supervisors in conducting reports with a coherent flow beginning with a problem, continuing with analysis and solution design, and finally ending with implementation.

KEYWORDS

Problem-based project, project-based learning, engineering design, design typology, standards: 2, 3, 5, 7, 8, 11

INTRODUCTION

Active learning, experience with design and implementation, and integrated learning experiences are key standards in CDIO. One of the most widely applied method for implementing these standards in educational practice is the *problem-based project.* Synonyms for problem-based project are capstone design course, challenge-based learning, and innovation projects. With few exceptions, traditional final projects in engineering education programs are also problem-based projects. Within the CDIO Initiative, many applications of Design-Implement Experiences are often pedagogically conducted as problem-based projects.

In a problem-based project, a student team solves a problem. A problem in engineering is usually constituted by either an improvement potential with an existing entity (e.g. an app with a too long launch speed) or that someone has a need for a currently non-existing entity (e.g. a manufacturer needs a robot). In problem-based projects, a student team develops an engineering design that constitutes the solution to the problem. For example, developing the app so the launch speed is faster or designing the robot that the manufacturer needs.

In many engineering education programs, students cooperate with an industrial partner, for example a manufacturer, a power plant, or a software developer. The project's problem usually resides with the industrial partner.

Engineering designs take many shapes. Civil engineers design buildings and bridges, manufacturing engineers design production and logistics systems, software engineers design programs and algorithms, and chemical engineers design chemical processes and products. The list exemplifies how engineering solutions are different across disciplines. Engineering solutions do also exhibit similarities. Two examples: (1) a solution meets design requirements and (2) a solution solves the project's problem. However, beyond these two examples, the nature of (good) engineering designs is under-explored. The purpose of this study is to contribute to the understanding of the nature of engineering solutions in problem-based projects *across disciplines.* Specifically, the study has two research questions (RQs):

RQ1: What are the characteristics of engineering solutions in problem-based projects?

RQ2: Which engineering solution archetypes do students develop in problem-based projects?

Through interviews with educators across engineering disciplines, the study first identifies the general characteristics, similarities, and differences of engineering solutions across disciplines. Second, the study uses these characteristics, similarities, and differences to create a *typology* of engineering solution archetypes.

In an earlier study, this paper's first author examined what external examiners considered the key challenges and success criteria for great projects. The discussion with the external examiners kept coming back to the one key challenge of ensuring coherence between project elements. Students must ensure a coherent flow between the structural elements of a project (problem, analysis, solution design, test, and implementation). Students struggle with the fit between (1) problem and analysis, (2) problem and solution, (3) analysis and solution, and (4) solution and the methods for assessing feasibility and planning implementation and operation. The solution is part of three of these struggles.

A typology of engineering solution archetypes creates awareness. If a student team knows which solution archetype they develop, they are better equipped to make decisions that ensure a coherent flow throughout the project. For example, whether their archetype can logically address the project's problem and how the results of their analysis should be applied in the team's solution design.

Understanding engineering solutions in problem-based projects is especially useful for cross-disciplinary projects that do not provide students with discipline-specific standards and methods. Applications of CDIO's Design-Implement Experience often integrate several disciplines in solving one problem, so the typology would provide a guideline currently not existing.

The remainder of this study is organized as follows: First, the literature review examines the characteristics of solutions in problem-based projects described in extant research. Second, the paper describes the study's methodology. Third, the paper presents findings including the typology of engineering solution archetypes. Fourth, the paper discusses implications, and provides conclusions.

LITERATURE REVIEW

The objective of this review of relevant literature is identifying the characteristics of engineering solutions in problem-based projects in engineering education. The study searched for relevant sources in Web of Science (Core collection) using the following search string:

> (TS=("engineering education" AND "problem-based" AND project AND (solution OR design))) *AND* **LANGUAGE**: (English) *AND* **DOCUMENT TYPE: (Article)**

The search results show that solutions are not dealt with across disciplines on an abstract level, but rather tangibly and discipline-specific. Recent examples are Gadhamshetty *et al.* (2017), who examine project-based learning in renewable energy technology, Dulekgurgen *et al.* (2016), who examine design projects in environmental engineering, and Santos-Martin *et al.* (2012), who present the experiences of problem-based projects about electrical components in wind turbine technology.

A few studies in the sample deal indirectly with characteristics of solutions in problem-based project in engineering education. Holgaard *et al.* (2017) have designed a five-step problem formulation sequence. As part of the five steps, Holgaard and her coauthors mention a number of characteristics of a good solution:

1. The problem formulation process defines a "solution space" that sets limits to what can constitute a solution to the problem
2. The problem (if formulated correctly) will "direct the problem solving process"
3. The problem formulation must include success criteria and demands from the solution

In further steps beyond the problem statement, Holgaard *et al.* (2017) state that student teams should "use relevant theoretical perspectives and models" to ensure that solutions meet the demands.

A search in the CDIO Knowledge Library using "problem-based" as search string returns 18 hits. Edström and Kolmos (2012) examine the differences between CDIO and PBL. While their study is comprehensive, it does not provide an explicit set of characteristics for solutions in either CDIO or PBL. Malherio *et al.* (2015) describe solution building as the most critical phase in engineering and that engineers must not simply find the right solution, but also build it. Malheiro and colleagues describe solution design within CDIO as 1) idea generation, 2) idea selection and substantiation, and 3) prototype development. The study does, however, not provide explicit descriptions about the nature of a solution. The present paper adresses this gap in engineering education literature.

METHODOLOGY

Given the scarcity of explicit characteristics of engineering solutions in extant literature, the study applies an inductive, interview-based research design.

To facilitate a base for interview discussions, the study develops an interview guide consisting of issues related to (1) project work in general and (2) engineering solutions in particular. The first part of the interviews concerned general issues such as when and how educations apply problem-based projects as pedagogical method. Examples of question are:

1. "How do you use project work in the education that you work with?"
2. "Could you characterize a typical project process that your students go through during a semester?"
3. "How do students apply theory, methods, and models in a project?"

These are general questions that contribute to a broad understanding of how educations use project work as a learning methodology. The second part of the interviews concern engineering solutions. Topics for discussion were among others what constitutes a solution, how students develop solutions, how solutions match with problems and analyses, and how students evaluate, implement and operate solutions. Examples of questions are:

1. "What do consider an analysis?"
2. "How does a solution fit with the analysis
3. "How are decisions made in the design process?"

The total set of issues is based on the two authors' prior experience with project course design, supervision, coordination, development. However, during interview rounds, the interview guide was developed further to reflect the totality of knowledge gained throughout the entire study.

Sample of interviewees

Interviewees were 20-25 education directors and experienced instructors from three Danish universities (Technical University of Denmark, University of Southern Denmark, and Aalborg University). Although all interviewees were employed by Danish universities, several interviewees were non-Danish nationals with experience from non-Danish engineering education. In addition, the sample included external examiners from industry.

Study procedure and protocol

The study first interviewed one set of educators within mechanical and manufacturing engineering. In the second round, the set of interviewees was expanded to include educators from other engineering disciplines (construction, chemical engineering, business engineering, and software engineering).

During both interview rounds, the study inductively identified characteristics, similarities and differences of engineering solutions across engineering disciplines.

Using the identified set of similarities and differences, the study developed a typology of engineering solution archetypes. The focus was on archetypes relevant for educational practice and not general engineering practice, where academic requirements do not apply.

Using interview data, the two authors developed a set of engineering solution characteristics and a set of engineering solution archetypes. Much interview data was discipline specific. For example, many interviewees provided examples of specific projects form their field. The role of the two authors was to condense the data and extract more abstract, cross-disciplinary answers to the study's two RQs.

The analytical reasoning of the typology development

Within manufacturing engineering, projects often concern improving an existing entity (usually a process of some kind) by (1) selecting a problem, (2) identifying causes, and (3) designing a set of policies, tools, procedures, etc. that address each cause. The solution is therefore a set of differing elements. When interviewing mechanical engineering lecturers, projects often concern developing a new entity (e.g. a new engine or machine component). In such a project, students (1) analysis the user need, (2) specify the design requirements, (3) analyze the subsystems or functions of the entity, (4) identify possible technologies for each subsystem, (5) design a solution by picking one technology for each subsystem). The project's solution is not a set of elements as in the prior example, but one logically constructed entity adapted to a set of design requirement. When discussing these results with civil engineering educators, their answers resembled the answers by the mechanical engineering lecturers, but with one critical difference. A solution often consists of not one, but two or more conceptual solutions that each meet design requirements to a varying degree and at a varying cost. The team, their industrial partner, and occasionally a construction client must choose one of the developed solutions, which the student team later specifies in detail. When discussing these solutions with lecturers from software, electric, and chemical engineering, the typology appeared complete. See the description of each archetype in the paper's findings section.

FINDINGS

This section addresses the study's two RQs. First, the section presents the general characteristics of engineering solutions in problem-based projects in engineering education. Second, the section presents the study's typology of engineering solutions.

General characteristics of engineering solutions in problem-based projects

The study has found that regardless of engineering discipline (e.g. chemical engineering or mechanical engineering) engineering projects are not concerned with conducting traditional research that answers unanswered questions about the world, but with developing solutions to problems. If a project designs a house, develops an algorithm, or constructs a liquid separation process, then the house drawings, the finished algorithm, and the constructed liquid separation process each constitute the project's solution. To draw the house, develop the algorithm and construct the separation process <u>is</u> to design a solution.

The following three subsections describe the study's results. The three subsections concern 1) the requirements of an engineering solution, 2) the basic nature of a solution, and 3) the relationship between the solution, on the one hand, and the project's problem and analysis, on the other hand.

Requirements for an engineering solution

The study has found the following general requirements for a good engineering solution:

1. The solution is based on the results of the project's analysis
2. The solution meets the requirements of the industrial partner
3. The solution is implementable both technically, practically, and economically with the industrial partner
4. The solution meets the university's requirements of a good solution
5. The solution will credibly solve the problem of the project

In addition to these requirements, there are a set of "nice-to-have" desirable characteristics, that the solution is beautiful, exciting, and perhaps a bit surprising.

The nature of an engineering solution

In a problem-based project, the study has found that an engineering solution is a *decision hierarchy*. Although the practice of conducting a project often is an iterative and complex process, the *formal* process of designing a solution means making a number of decisions in a logical sequence. Together, the total set of decisions forms a design decision hierarchy. In the decision hierarchy, some decisions are superior to others. Figure 1 illustrates a decision hierarchy.

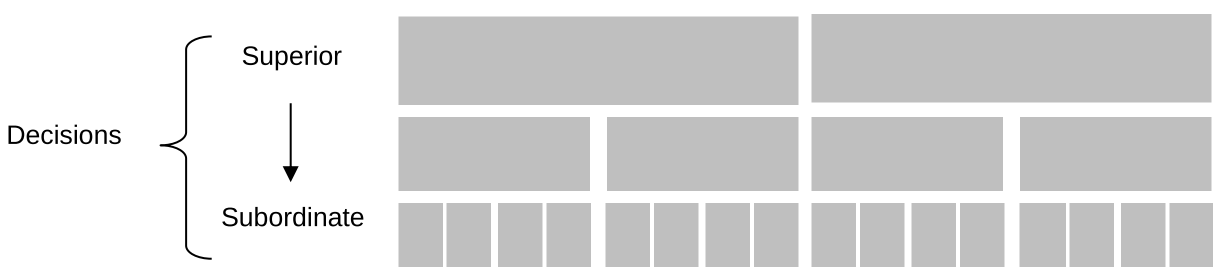

Figure 1. The solution is a decision hierarchy

The superior decisions, which concern overall issues, are taken early in the project period. These decisions limit the decision space for the subordinate decisions that concern issues of higher detail.

For example, if building a house, the first decisions by the architect concern the outer dimensions of the house. These dimensions limit the decisions concerning ground plan and staircases. These decisions are superior to decisions concerning the interior design of the kitchen, living room, bathrooms, etc. The most subordinate decisions in decision hierarchy concern the most detailed decisions. In a house, these decisions concern e.g. power outlets, ceiling material, bathtub design, etc.

The relationship between the project’s analysis and the solution

Projects, where the problem is an improvement potential in an *existing* entity, conduct an analysis of the root causes of the project’s problem. The solution then either eliminates the root causes or reduce their impact on the problem, and thus solves the problem. For projects, were the problem concerns designing a *new* entity, the analysis does not find root causes, but instead identifies all relevant design requirements for the solution. The project team then designs a solution that meets these design requirements.

Typology of engineering solution archetypes

When examining solutions across disciplines in problem-based projects in engineering education, the study has identified three solution archetypes. These archetypes are labelled 1) the adapted solution, 2) the “either/or”-solution, and 3) the multiple-elements solution. Figure 2 illustrates the three archetypes and provides an example.

The adapted solution	**The ”either/or” solution**	**The multiple-element solution**

Example: An app developed through an iterative process that adapts to all requirements from the industrial partner.	Example: A suspension bridge, a cable-stayed bridge, and a tunnel are three alternative connections between an island and the mainland. The industrial partner (often a construction client) must choose “either-or”	Example: The study has selected three out six potential elements. Together, these three selected elements constitute the solution to a problem (see a specific example in paragraph below)

Figure 2. The typology of solution archetypes

Figure 2 shows the study’s typology, which consists of three archetypes. The adapted solution is constituted by a single, comprehensive entity. A single, comprehensive entity could be a bridge, a machine, or an app. The “either/or” solution first develops two or more single entities that (each) function as a solution, but with varying degrees of effectiveness, cost, and ease of implementation. The multiple-elements solution consists of several solution elements that each address a cause for the projects problem. Example: A project deals with a high failure rate from a production process. The project has analyzed the root causes and identified a set of three elements that together vastly reduce the amount of failures. The set of elements are (1) clearer assembly instructions, (2) a stricter component control procedure, and (3) a higher frequency of production equipment maintenance.

The following three subsections describe the three archetypes in more detail.

The adapted solution

The adapted solution emerges from a design process, where the student team first identifies the design requirements and then develops a solution that fits with the requirements. The design process can be either sequential or iterative where the student team identifies and specifies design requirements not only prior to but also during the solution design process. These requirements are often technical (e.g. a product must endure 24h use), legal (e.g. a filling machine in the pharmaceutical industry must provide documentation for each batch), and derived directly from users or customers (e.g. a building must be heated with a heat pump). The adapted solution is often applied in software development and development of mechanical products. In software development, the success criteria of an app relate to how well the app meets the design requirements (often from future users of the app).

This solution fits well if the project's problem concerns the development of a new entity. The adapted solution is evaluated by how well the solution meets design requirements, costs and ease of implementation. The solution is usually implemented in one piece rather than bit-by-bit.

The "either/or" solution

In some fields, a solution is not one single entity that is adapted to a set of (often emerging) design requirements, but rather a *set* of several single entities. Figure 2 provides an example from civil engineering. The student team develops three different solutions and the construction client will then select "either/or".

In addition to designing two or more solutions, the "either/or" solution includes a subsequent analysis of how well each alternative solution meets the design requirements, and also often how much the solution costs to implement and the ease of implementation.

As with the adapted solution, the "either/or" solution fits well if the project's problem concerns the development of a new entity. The "either/or" solution is evaluated by how well the solution that is selected meets design requirements. In addition, costs and ease of implementation are often included in the selection. The selected solution is usually implemented as one unit rather that piece-by-piece.

The multiple elements solution

A multiple-elements engineering solution consists of a selected set of elements that together comprise the solution to the problem. The basis for designing a multiple-elements solution is not an identified and specified set of design requirements, but instead an analysis of the root causes of the project's problem. Beginning with the project's problem (e.g. many failures in a production process), the analysis works its way through a set of cause-and-effect trajectories. These trajectories lead to the root causes of the problem (root causes could be unclear assembly instruction and defective components). A student team often designs several solution elements that differ in effectiveness, cost and ease of implementation. The project then selects a group of elements for further study and finally implementation.

The multiple-elements solution differs from the two previous archetypes in several ways: 1) what the multiple-elements solution will be is unknown prior to the root cause analysis, 2) the solution often consists of elements that are intuitively unrelated, and 3) the solution is evaluated, implemented and operated on an element-by-element basis rather than as one comprehensive unit.

The implementation of the solution must consider interdependencies among solution elements when selecting solutions elements for the final solution. Furthermore, the student team should consider whether solution elements should be implemented all at once, element by element, or in “waves”.

CONCLUSION AND DISCUSSION

The study has identified the general characteristics of engineering solution and developed a typology of three engineering solution archetypes. These archetypes are labelled 1) the adapted solution, 2) the “either/or”-solution, and 3) the multiple-elements solution. Figure 2 illustrates the three archetypes and provides examples.

The typology vis-à-vis extant research in the CDIO initiative

Within the CDIO Initiative, Carmard et al. (2013) and Malmquist et al. (2015) present two project frameworks labelled Innovative Conceptual Engineering Design (ICED) and Challenge-based Learning, respectively. ICED focuses on core engineering skills, Challenge-based learning focuses on societal challenges, and both concepts are very ambitious with respect to the magnitude of the problems that projects solve ranging from technical challenges (e.g. spacesuits and habitats for Mars missions) to sustaining life on earth (e.g. providing energy from fusion and improving urban infrastructure). While ICED primarily develops what the present labels the adapted solution, the Challenge-based framework frameworks integrate all three archetypes, but appears to focus mostly on the multiple-elements archetype that solves root causes to problems.

Value of typology for educational practice

For students and educators, the typology promotes awareness. If a student team knows their project’s problem, they can better identify the solution archetype that fits with their problem. When knowing the archetype, students will better understand:

1. The relationships between the solution and the project’s analysis on the one hand, and the solution and the implementation on the other hand
2. How to evaluate the feasibility and the nature of solution implementation and operation

Study limitations and future research

The study is built on educator interviews only. A future study could test whether examining 100 actual projects across engineering disciplines would lead to the same three archetypes. Such a study would have to control for possible bias (the risk of identifying what the researchers already know, i.e. the archetypes in the current study).

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BIOGRAPHICAL INFORMATION

Samuel Brüning Larsen, PhD, is an Associate Professor in the Center for Bachelor of Engineering Studies at the Technical University of Denmark. He primarily teaches operations and supply chain management to B.Eng. students. He is coordinating several integrated cross-disciplinary courses, conducts and supervises projects with industry, and works with cross-disciplinary innovation.

Per Valentin Bigum is an Associate Professor in the Center for Bachelor of Engineering Studies at the Technical University of Denmark. He primarily teaches manufacturing technology and mechanical engineering. He is coordinating several integrated cross-disciplinary courses, conducts and supervises projects with industry, and works with cross-disciplinary innovation.

Corresponding author

Dr. Samuel Brüning Larsen
Technical University of Denmark
Lautrupvang 15
2750 Ballerup, Denmark
+45 2970 7544
sbla@dtu.dk

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MAPPING ARCHITECTURAL ENGINEERING STUDENTS' LEARNING IN GROUP DESIGN EXERCISES

[1]Fischl, G., [1]Granath, K., [2]Bremner, C.

[1] Jönköping University, Department of Construction Engineering and Lighting Sciences, Jönköping, Sweden

[2] Charles Sturt University, School of Communication and Creative Industries, Wagga Wagga, Australia

ABSTRACT

Architectural engineering encompasses urban planning and architectural design exercises that are part of professional development. In contrast to the engineering discipline, the regularity of well-defined familiar tasks does not predominate in a design studio. However, to be able to work along with a larger pool of professionals and increase the potential for creative problem solving it is imperative to provide an engineering education that challenges the conventions of its framework. Consequently, students encountering design problems without prior experience need to assume responsibility for their interpretation of the problems in which they are being challenged. The aim of this pilot study was to survey, describe and analyze the problem-solving approach among undergraduate students in relation to their control strategies and successive learning. The study was completed in Jönköping, Sweden. In an online survey (N=32) using convenience sampling, students' locus of control (LOC) as the measure for control strategies over their learning situation was assessed in three school years within the undergraduate program. Additionally, three focus group interviews were performed to shed light on how individual learning modes manifested on different LOC levels and in respective school years. Descriptive statistics showed a trend that students' LOC is moving from external to be more internal by the advancement in their studies. Accordingly, they would over time develop a preference for group design exercises that are more problem-oriented, rather than assignment-based, thus matching a more internal LOC. Although the trend was clear, statistically significant differences were not found between the measured variables (LOC, gender, age, school year, subject major), possibly due to the low sample size. The focus group interviews supported the trend, where students' initial frustration over unclear instructions and dependence on external control gradually shifts toward a more reflective attitude and a greater feeling of internal control, individual competence and professional development.

KEYWORDS

locus of control, architectural-engineer, learning outcomes, problem-solving, active learning

INTRODUCTION

As the CDIO initiative (Crawley, 2001; Crawley, Malmqvist, Ostlund, & Brodeur, 2007) states, in contemporary undergraduate engineering education seems to be a conflict between the need for technical knowledge and personal and interpersonal skills that young engineers must possess for successful team work and product realization. One of the personal traits that have been investigated over decades in diverse groups of people is the construct of the locus of control (LOC). Initially, Rotter (1954) introduced the term and referred to it as an individual's perceived control over their environment. Nowicki and Strickland (1973) elaborated upon the Rotter's LOC concept and included reinforcement as an important determinant of behavior for children's learning "appropriate social and personal behavior" (p. 148). In the process of finding appropriate behavior during a learning period, individuals must go through the problem-solving stages as Elliott, Godshall, Shrout and Witty (1990) defined in a five-stage process: general orientation, problem definition, the generating of alternatives, decision-making, and evaluation. To solve a problem, individuals must possess self-confidence and determination to achieve the goal under their control (Pretz, Naples & Sternberg, 2003), otherwise when individuals think that the solution for their problem rests outside of their control, their motivation decreases and it requires external intervention for them to succeed. Consequently, individuals with internal LOC are more effective problem solvers than individuals with external LOC (Pretz *et al.*, 2003; Konan, 2013). The internality and externality of LOC refer to the individual's orientation toward reinforcement possibilities (Çakır, 2017). When the CDIO initiative talks about problem-solving in the context of personal and professional skills, LOC can be a mediating variable for developing successful problem-solving skills in young adult students.

Architectural engineering is a field that combines engineering with the principles of design to establish functional and usable constructions. Its graduates work with a specific problem-solving approach that on one hand, originated in science-based education and on the other hand, deals with project specific open-ended problems both in planning and execution. Most architectural engineering education is a three-year bachelor's degree and encompasses urban planning and architectural design exercises as part of professional development. This problem-solving approach can then be further specified as facilitated either through an assignment, a subject project, or a problem-based learning activity (Kolmos, 1996). The underlying concept behind these categories is to focus on learning instead of teaching (Kolmos, 1996). The features of problem-based learning encompass active student participation with authentic task identification, which in turn will serve as a vehicle for future learning (Stefanou, Stolk, Prince, Chen and Lord, 2013). In this way, students determine what they need to know as well as where and how to find the critical information, hence they constantly monitor their learning and understanding of the problem. A supporting collaborative team is essential in this case for pushing and challenging each other into a deeper understanding. Teachers are at the disposal of the students to provide assistance and feedback along the learning process that builds up a culture of acquiring knowledge. In contrast to this, assignment-based learning originates in the application and integration of knowledge to a specific task in which students receive well-defined course works and time management requirements.

At Jönköping University in Sweden, the program in architectural engineering accommodates urban planning and architectural group design exercises for approximately one fourth of the total program credits (180 ECTS) in the form of compulsory and elective courses. They are an integral part of the program, together with the subjects on building physics, building materials theory, structural mechanics, structural engineering and construction technology.

Within the program of architectural engineering, initiatives were taken to map and analyze students' orientation toward perceived control and its relationship to a problem-solving approach. Hence, the purpose of this pilot study became to survey, describe and analyze the problem-solving approach among undergraduate students in relation to their control strategies for successive learning in group design exercises in the architectural engineering program. To visualize the findings, the locus of control survey - intended to be used as an indicator for the control strategies - positioned the individuals or groups on the vertical axis, whereas the student's experience of the design exercises was indicated between an assignment- and a problem-based exercise continuum on the horizontal axis.

METHOD

The pilot study employed a mix-method technique; the quantitative part included the measurement of LOC while the qualitative investigation entailed focus group interviews.

Participants

In the quantitative study part, altogether 155 students were approached for participation, including four students in the construction-engineering track, and 151 architectural engineering students. The response rate was 20,6% resulting in 32 participants (M_{age}=22.79; SD_{age}=3.219) with an evenly distributed gender profile. In terms of school year, the first-year students were 10, second-year students were 18, and the third-year students were only four. Among these students, 28 studied in the architectural engineering track, while four studied in the construction-engineering track.

The focus group interviews in each school year included four students, in total 12 (M_{age}=23.75, SD_{age}=4.45) and among them two females studied in the third year of the architectural engineering track. In terms of study tracks, two students were in the construction-engineering track in the first year, while the others studied in the architectural engineering track. For the focus group interviews, participant selection employed convenience sampling method using personal contacts within the ongoing academic courses. All twelve students participated in the LOC measures as well. Participants in the focus group interviews were rewarded with a lunch for their efforts.

Data collection instruments

An internet-based Nowicki-Strickland (1973) locus of control questionnaire was administered in the quantitative research part, in which a 40 forced-choice item is organized to measure the individuals' internal or external positions regarding their generalized control expectations. Additional measures of students' demographic data (age, gender) and their subject major were recorded together with research consent for ensuring an ethically conducted investigation.

Focus group interviews were conducted using a protocol including introduction of the topic and guidelines for interactions to ensure effective communication. The length of each interview was half an hour. A semi-structured interview was administered, and audio recorded, then transcribed. The interview questions were organized according to Kolb's (1984) experiential learning styles that incorporate four main learning modes (concrete experience, reflective observation, abstract conceptualization, and active experimentation). Questions targeted previous concrete learning experiences in group design exercises and perceived conflict and control during tasks; the questions on reflective observations entailed assignment- and problem-based exercises and issues of grading. Furthermore, students' abstract observation mode was probed by asking them to reveal how to deal with a situation that requires individuals with different skills and knowledge level, and finally a question on active experimentation mode asked how a student would use these experiences in future situations.

Procedure

Students in three architectural engineering courses responded to an email link for the Nowicki-Strickland questionnaire including inquiries on demographic data and the research consent. This questionnaire was formed in Google Forms and made available online. After agreeing to the research consent, the participants could complete the entire questionnaire online. There were three focus group interviews conducted in groups of four students and two researchers at the time, one group for each respective school year. The interviews were audio recorded, then transcribed and analyzed following the data analysis procedure.

Data Analysis

The scoring procedure of the Nowicki-Strickland questionnaire provided interval data and could be treated parametrically. The information on subject major, and gender was gathered as nominal data while age as ratio and school year as interval. The explorative data analysis employed independent t-tests, one-way ANOVA and non-parametric tests for correlation.
A content analysis of the transcribed interviews was performed using a deductive technique. The interview data was structured in three main domains. Firstly, the data was extracted to describe a position for each individual student on an assignment/problem domain, in which the perceived openness or the level of prescription of the group exercises could be located. These categories became assignment-oriented, ambivalent or problem-oriented. Secondly, the combined interviews were ranked by respondents' LOC to render the students' perspectives on learning styles irrespective of their school year. Consequently, students were categorized in internal (LOC≤6), ambivalent (LOC=7-12) and external (LOC≥13) LOC. Finally, a word frequency analysis was performed to shed light on trends of using words for expressing learning style and attitudes towards group design exercise in the respective school years.

RESULTS

The quantitative data analysis for the total sample (N=32) was intended to reveal statistically significant differences with a range of exploration on the LOC measures as dependent variables. However, the analysis did not show significant differences between LOC and subject major, school year and gender. A summary of descriptive values is presented in Table 1. The Pearson correlation showed a weak negative association between school year and LOC ($r=-0,349$, $r^2=12\%$) wherein the correlation coefficient is significant at $p=.050$.

Table 1. Summary of LOC scores using descriptive statistics (N=32).

IV	Levels	N	M	SD
School year	1	10	12,40	3,89
	2	18	9,78	3,02
	3	4	9,00	4,16
Gender	Male	16	10,13	3,91
	Female	16	10,88	3,30
Subject major	AE	28	10,61	3,78
	CE	4	9,75	1,71

Note: IV=Independent variable, AE=Architectural engineering, CE=Construction engineering

Additional descriptive analysis was gathered for the focus group (N=12) sample. In this analysis, the individual scores on LOC were positioned and categorized according to their value on the internal-external domain (low≤6, 7<medium≤12, high≥13) as it shows in Figure 1.

In this pilot study, there were correspondences between LOC and learning styles. Learners with high LOC show preference for assignment-based learning, and vice-versa, students with low LOC show preference for problem-based learning. Over the three years, the tendency is a falling LOC, leading to a more internal control, and a tendency where preference move from assignment- to problem-based learning.

A second year external LOC (13) comment reveals that the student is moving into unchartered territory fearing unclear expectations, while the student's understanding is confronted with a new situation:

> "I think, like, from school… I had no idea that people were so different… I always thought that what I see as correct, everyone else should also see as correct… I thought it was superstrange in the beginning, sort of…what? They don't think like I do…why…?".

A third year external LOC (14) comment shows that the student is struggling to organize and find control over a more open and independent project work situation in the last semester:

> "…it's just like with the final thesis now…when you are supposed to decide everything by yourself…you just want to go and ask everyone about everything…".

Another example elaborates upon a progression of the entire school period. It should not be counted as an extreme perspective on wishes and similarities, rather a matured, reflective first year ambivalent LOC (12) student that shows awareness of the progression:

> "…that's why I feel like….more regulated in the beginning, and then open up and let the students think for themselves, the more they have studied".

The next citation from a first year ambivalent LOC (10) student shows awareness of the learning process:

> "…but I felt like that now….in the beginning it went very slowly, you wanted to understand everything, you were so careful with everything and then you were lagging behind, and then at the end when you had understood everything and just like now I do this and now I do that...but it is also hard to make it even over

> time...you are in a state of learning in the beginning...you are sitting trying to figure out how the software works and how you thought and you make a sketch and then you drop it and start over, and then in the end you just: Finalize everything… Bang!”

A third year ambivalent LOC (9) student comments on an issue of understanding of the scope and limitations of the project with a strong feeling of ambivalence:

> “…at the same time, I can understand this about frustration….I can feel that… that some things really should have been more clear…should it be included or not…(long pause)… so it is very different…”.

The same student facing the option of having a course with an open problem:

> “…I must say, when I hear that question…undefined projects…instinctively, I feel a bit of fear…”.

At the internal end of the LOC scale, a comment from a second year LOC (4) student shows a growing understanding of a future professional role:

> “I think the experience of having worked project based continuously during the education is very good when you start to work, because as I understand it, in our profession you work in projects where every many different actors need to cooperate and coordinate the work. It’s not like hundred years ago, when an architect did the design and then the others had to solve everything else, but today everything must be coordinated in a different way. It becomes a bit like a dance, and then it is good that you have been dancing as a student.”

A third year internal LOC (4) student expresses awareness of his changed attitudes towards group design exercises:

“…as they say: if you want to go fast, you go alone, if you want to go far you should go together… and to me, during the first year I found it very hard to collaborate with people, but now I have developed a much better attitude on how to approach… distribute tasks, simply collaborate…”

Figure 1 shows the relative positioning of the LOC survey results according to the students experience of the design exercises. This visual presentation in a profound way shows the development the students are taking from a highly prescriptive assignment-based experience to a less prescribed problem-based experience, while their LOC is showing a more internal orientation. First-year students are concentrated in the upper left quadrant. In the second year, there is a drop in LOC, but still more preference for assignment-based learning.

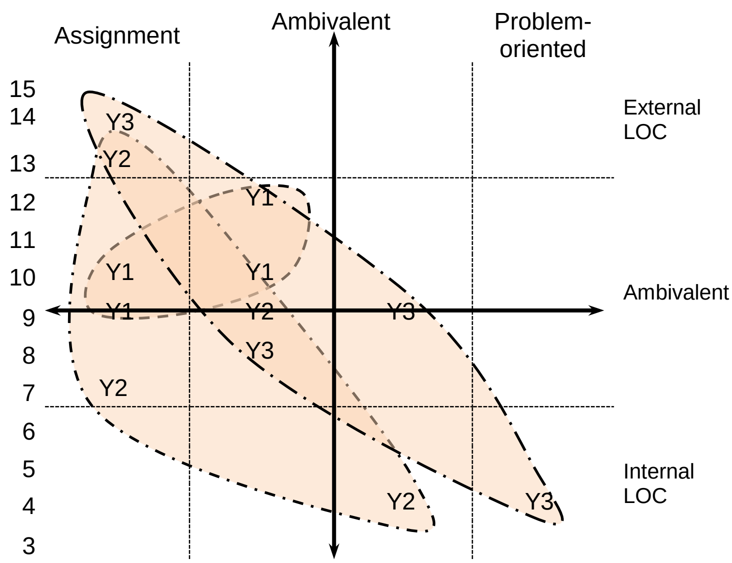

Figure 1. A summary of LOC position of each student and school year group with regards to problem-orientation. Note: Y1 means student in first year.

In the third year, the average LOC is dropping further, and preference for problem-based group design exercises have increased. The tendency shows LOC shifting from external to internal, and preferences moving from assignment- to problem-based design exercises. A section from the interview with the third-year students further illustrates this. Students are here identified by their LOC. In this excerpt, you can clearly see the competing forces between internal and external control, and the more ambivalent middle position.

LOC 4: "…no, but I prefer freedom…when you said that about problem solving, I think that is much more interesting… so absolutely, less teacher, sort of…"

LOC 8: "…it is hard to know, like, how far outside the box you may go… because you want to…you have, like in this task, things that have to be included…and then you want to include that, but how…. how much else you are allowed to do…as you say, if you are not allowed to do certain things... it is hard to know, because you want to do the task in a good way to get a good grade, you don't want to risk.... "

LOC4: "…to me it's also about taking the opportunity… for me, grades are not that important, I really don't care, I'd rather do something I believe in, and then whatever happens... "

LOC14: "…then it is just your own creativity stopping you…what may one do, what may I do…why didn't anyone tell that you were allowed to do like this…. "

LOC10: "…but at the same time, there I would perhaps never dare to take a chance "

LOC14: "…no, then you would want to discuss with your supervisor first, can you do like this, before…"

Additionally, a word frequency analysis included the 15 most frequent words in each focus group interview, whereof nine occur in all three. These words are: shall/must, do, some, then, may, think (as in have an opinion), more, also and different. The distribution of these words is shown in Table 2. For most of them, the change in ranking seems arbitrary, however some of the changes are worth highlighting.

Table 2. Word frequency count on the nine most often used words

Ranking	Frequency	1st year	Frequency	2nd year	Frequency	3rd year
1	41	shall/must	47	some	31	may
2	21	do	35	shall/must	29	think (have an opnion)
3	19	some	31	maybe	29	some
4	18	then	22	more	26	want
5	15	maybe	21	different	26	shall/must
6	15	may	19	also	25	do
7	14	think (have an opinion)	19	do	23	more
8	14	more	19	may	22	also
9	13	also	18	good	20	different
10	13	think (mental process)	17	think (have an opinion)	19	some
11	11	different	17	just	16	then

In the first year, shall/must is the most frequent word used, whereas may and think come in as number 6 and 7. In the second year, shall/must is in second place, and may and think drop down to place 8 and 10. But in the third year, may and think are propelled up to first and second place, while shall/must drops down to place 5. This indicates that first year students, in this semi-structured interview situation with identical main questions to all groups, talked significantly more about what they felt they shall or must do, and less about what could be done (as in may), or what they wanted (as in think or want). The same pattern can be found among second year students. In the third year, students talk much more about what they may do, what they want and what they think about it, and substantially less about what they shall or must do.

The actual frequency also mirror this pattern. In the first year, the top word shall/must is used almost twice as much as the next word, do (41-21 instances), whereas in the second year, the frequency difference between number one (some) and number two (shall/must) is twelve (47-35 instances). Finally, in the third year, the frequency difference between the two most used words, may and think, is just two (31-29 instances), and must/shall has dropped down to 26 instances, sharing fourth place with a completely new word, want (26 instances), further strengthening this tendency that the discourse in the third year has moved from external to a higher degree of internal control, or from being controlled to be in control.

DISCUSSION

Students in architectural engineering studies find themselves between two often-competing disciplines; engineering is generally a more prescriptive field while architecture is prone to less prescription. Students of this blend experience conflicting information during the advancement of their studies, which in turn can be the source of frustration and problems for managing interpersonal skills, project management and successful project delivery. This pilot study attempted to survey, describe and analyze the problem-solving approach of the students in relation to their control strategies to a successive learning.

The quantitative analysis had less tangible results in this study, due to the limited sample size. The descriptive statistical results on the school year LOC, however illustrated a trend toward a slowly shifting locus of control - from being external to more internal. This is in line with CDIO's suggestion about young learners' interest for feeling responsibility and ownership over their professional development. The response rate on the online survey is considered moderate, however leaving plenty of room for improvements not only in the attractiveness of the survey, but also the appropriate data collection technique.

The focus group interviews proved to be fruitful. Due to the semi-structured interview technique, a full circle of the learning style could be covered with additional probing questions. The first-year students in the focus group represent a more coherent group in terms of their LOC and problem-solving approach that locates them in the context of following instructions and satisfying the course requirements. Students belonging in this group seek to maintain a status-quo between their internal motivation and the external factors, like intended learning objectives of the design exercise in order to manage the complexity of the new situation. Meanwhile, the second-year students show a deviation from the dependent behavior that was represented in first year. Students here are more performative, exploring and utilizing their resources and motivations to excel in design exercises and occasionally finding a reason to even challenge it. Finally, students in the third year are experienced in the form of design exercises within architectural engineering. Their individual position on the problem-solving approach is more distinct compared to the first year; conversely some of them are ambivalent toward a clear preference for what extreme position they could occupy on the problem-solving approach. It is a delicate situation when a person is located in the middle range of ambivalence, because the possibility to shift oneself to a more problem-oriented approach together with an increase of externality in LOC can result in a status, wherein the feeling of being lost dominates. Conversely, the intention of a group exercise in architectural engineering would be to maintain a performative approach and, in the meantime, shift toward a creative (internal LOC and problem-oriented) phase where students can optimize their learning in design exercises. As one student mentioned it, this is like a dance and they are benefiting from it, when they are dancing as students.

CONCLUSION

The exploration of LOC and problem-solving approaches in architectural engineering group design exercises has shown a variety of results. As expected, students in the progression of the undergraduate level would prefer group exercises that move from being assignment-oriented in the beginning of the studies, to become more problem-oriented in the later years. A carefully designed education progression could also stimulate a gradual internalization of LOC, thus helping students to develop independent professional skills. The trend for this was observable, however, statistically significant differences were not found between the measured variables. The focus group interviews supported this trend, where students' initial frustration over unclear instructions and dependence on external control gradually shifts toward a more reflective attitude and a greater feeling of internal control, individual competence and professional development. A remark must be made concerning the ambivalent positions, that the risk of slipping into a higher LOC and low-prescriptive design exercise may increase the feeling of being lost. A continuous mapping of students LOC could be used as a tool to provide information when revising the educational programs and the curricula. From an educator perspective, the desired development over time would be to observe the students to develop - both as a collective and as individuals - from assignment to problem oriented and from external to internal in locus of control.

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BIOGRAPHICAL INFORMATION

Géza Fischl, PhD is an architect and senior lecturer at Jönköping University. His field of research entails architectural/environmental psychology and evidence-based design.

Kaj Granath, PhD is an architect and senior lecturer at Jönköping University. His research is concentrated around housing and urban planning, with a special focus on functional aspects and client values.

Craig Bremner, PhD is Professor of Design at Charles Sturt University. Prior to this he has been a Professor of Design at the University of Southern Denmark; Northumbria University UK, and the University of Canberra. His research deals with developing methods to discover and to value why 'not-knowing' is an essential beginning point of design practice.

Corresponding author

Dr. Géza Fischl
Jönköping University,
Box 1026
551 11 Jönköping, Sweden
figeza@ju.se

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FACULTY EXPERIENCES IN INTERDISCIPLINARY PROGRAMS: OPPORTUNITIES AND CHALLENGES

Åsa Gustafsson

Department of Accounting and Logistics, Linnaeus University, Sweden

Mirka Kans

Department of Mechanical Engineering, Linnaeus University, Sweden

ABSTRACT

Changes in the business environment (such as shorter product lifecycles, globalization, and digitalization) while contributing to a sustainable development, have formed new conditions for companies and organizations. In this new situation, problems encountered cannot be answered within a single discipline. Interdisciplinary programs where students from different disciplines interact in learning and knowledge creation is a way to meet these changes in society. An interdisciplinary program also requires interaction on staff level: Meaningful collaboration brings together expertise from different disciplines so the fundamentals of a given discipline are clarified, and the connections to other disciplines are described, reaching a synergy effect by utilizing the strengths of each area. This, however, puts demands on the curriculum design and on the interaction of the teachers. This paper explores the teachers' perspective of an interdisciplinary program at Linnaeus University. The program is a 2-year master program entitled "Innovation through business, engineering and design", recruiting students from the engineering, business and design disciplines. The teaching staff represents different subject areas, and the teachers interact in an interdisciplinary mode in the first year, while the second year mainly contains disciplinary courses. In two focus group interviews, teachers were asked about opportunities and challenges in participating in the interdisciplinary program, as well as their view and how interdisciplinarity is considered in the program. The purpose of the paper is to identify how teachers perceive teaching in an interdisciplinary program as well as to distinguish perceived opportunities and challenges for teachers to participate in interdisciplinary programs. This paper concludes that teachers perceive interdisciplinary learning to take place in the project context, where students come from different disciplines work together to solve a complex real-life assignment. Moreover, the hindrances appear to outweigh the possibilities in participating in an interdisciplinary program. Amongst challenges the teachers perceive lack of resources, such as appropriate learning environments, required competence, and unclear decision channels.

KEYWORDS

Interdisciplinar, Focus groups, Master program, Innovation, Standards 3, 7, 9, 10, 12

INTRODUCTION

The core at most university's missions is mainly education and consequently a majority of faculty time involves activities relating to students (Kennedy, 1997). At the same time one main task for universities is to conduct education meeting the needs from external stakeholders. Few of the questions posed by industry can be answered within a single discipline (c.f. Bolman and Deal, 2014, p 101). One way for universities to meet the needs from the industry is to develop and realize interdisciplinary programs (Gustafsson, 2015). The academic workplace is becoming increasingly complex (O'Meara, Rivera, Kuvaeva, and Corrigan, 2017). In general faculty members are dedicated to their work and in order to maintain a stable worklife, reducing complexity is needed (Johnsrud and Rosser, 2002).

The case, serving as an example throughout this paper, is an interdisciplinary two-year master program involving three faculties: the Faculty of Technology; the School of Business and Economics and the Faculty of Arts and Humanities hosted by Linnaeus University, Sweden (further on referred to as LNU). The program has been running for four years. According to Kans and Gustafsson (2016), the program holds the following dimensions of interdisciplinarity:

- **Student groups:** The students work together in groups with students from the other faculties/disciplines. Each group consists of an equal number of students from engineering, design, and business administration.
- **Problem/task for the student groups:** The briefs are interdisciplinary in nature and the students are expected to balance the different process parts with respect to function, design, durability, production conditions, and business administration. In order to do this, the students require knowledge of, and interaction between, different disciplines where different perspectives and approaches are utilized.
- **Faculty members, curriculum, and administrative task:** The students have facilitators from LNU including faculty members, curriculum, and administrative tasks; Faculty members hold lectures and provide tutoring both individually, and in interdisciplinary groups. The curriculum states that the students should be able to demonstrate an understanding of the increase in value of interdisciplinary collaboration. The administrative tasks are carried out together in order to solve the practical problems that appear, and to prevent future problems.

Interdiciplinarity will increase the ability to understand complex challenges (Annan-Diab and Molinari, 2017) and consequently there is and will be a need for teaching institutions to teach interdiciplinarity. Interdiciplinarity breaks traditional teaching structures and encompasses many aspects. For teaching institutions that want to be at the forefront, and keep a stable work environment for faculty members, the question arises; *how do involved teachers perceive interdisciplinarity, which are the opportunities and challenges?* The question constitutes the purpose of the paper; identify how teachers perceive interdisciplinarity as well as to distinguish perceived opportunities and challenges for teachers to participate in interdisciplinary programs.

METHOD

The focus group method is a well-known method for allowing researchers to examine how different people together interpret the general phenomenon that the researcher is interested in studying (Bryman and Bell, 2013). Focus groups are particularly suitable for studying perceptions in social processes (Sim, 1998). Consequently, empirical data to this study has been gathered through focus groups using open questions focusing on specific phenomenon (interdisciplinarity). Suitable participants in a focus group are members who were known to possess certain experience to be interviewed in an unstructured way about the experience (Bryman and Bell, 2013). The authors (of this paper) have an in-depth previous understanding of the program and its contents. Thus, they could take active part in the focus groups (Frey and Fontana, 1991). Teachers teaching at the program participated together with the interviewers and in total two focus groups were conducted with 8 faculty members. The interview guide is presented in Appendix 1. The interviews were held in both English and Swedish and hence the quotations either stem directly from respondents or have been translated from Swedish to English. Further the interviews were recorded and transcribed. The authors applied the analysis method of patterns of association (Bryman and Bell, 2013) where they mapped empirical data with theoretical concept, first individually and thereafter comparing the results with each other. Both of the authors had done the mapping in the same manner and consequently validity was achieved.

THEORETICAL FRAMEWORK

The definition of interdisciplinarity

In Table 1, an overview of different definitions is given together with authors' comments describing the main focus of the definition.

Table 1. Definitions of interdisciplinarity

Source	Definition	Authors' comment
Meeth (1978)	Interdisciplinary programs attempt to integrate the contributions of several disciplines to a problem, issue, or theme from life. In interdisciplinary studies integration means bringing interdependent parts of knowledge into harmonious relationship. It involves relating part to part, part to whole, and whole to part.	Focus is on the **integration of disciplines** for solving a problem.
Roger et al. (2005)	the emergence of insight and understanding of a problem domain through the integration or derivation of different concepts, methods and epistemologies from different disciplines in a novel way	Focus is on the **understanding** of a problem **through integration** of disciplines.
Porter et al. (2006)	a mode of research by teams or individuals that integrates • perspectives/concepts/theories, and/or • tools/techniques, and/or • information/data from two or more bodies of specialized knowledge or research practice	Focus on the **integration of disciplines**.
Davies and Devlin (2007)	integration of two or more disciplines in the education	Focus on the **integration of disciplines**.
Pharo et al. (2012)	the integration of disciplinary perspectives to produce insights that are more than the summing of disciplinary knowledge	Focus on the **integration of disciplines** to create insight.

A common determinator in all definitions is the integration of disciplines. The definitions differ in respect to why this integration is made. Some definitions only identify that integration is made (Porter et al, 2006; Davies and Devlin, 2007), while others also identify problem solving as an area for the integration (Meeth, 1978; Roger et al. 2005). The intention is indicated in two of the definitions (Roger et al., 2005; Pharo et al. 2012), i.e. to create deep knowledge by integration of disciplines. Synthesizing the definitions, interdisciplinarity could be seen as *the integration of disciplines as a means to create deepened knowledge of a problem*.

Opportunities and challenges as reported in literature

Interdisciplinary education is facing a number of challenges. For the individual participant **intellectual challenges** arise in terms of conflicting terminology and perspectives (see Boden et al., 2011; Turner et al., 2015). The disciplinary language, theoretical constructs and preferred methods might differ from those of the other participants, and those applied in the interdisciplinary setting. In addition, a schism between disciplinary work and interdisciplinary work exists. Disciplinary work is seen as the natural mode of research and interdisciplinary work seen as an addition to disciplinary work rather than a legitimate basis for research. This gives rise to “addition transaction costs” for those who involve themselves in interdisciplinary settings (Sá, 2008). In addition, **organizational challenges** are often at hand according to Boden et al. (2011). Universities are structured according to disciplinary thinking; resource allocation, decision channels and reward systems are based on disciplines, which makes it hard to align and support interdisciplinary initiatives. A crucial resource is time, as interdisciplinary education tend to consume more time than traditional education (Pharo et al., 2012). Another important resource is financing. Due to current scholarly reward systems, promoting disciplinary research, it could be hard to convince scholars to participate in interdisciplinary collaborations, especially those in their early careers, (Sá, 2008;Turner et al., 2015). Schmidt et al. (2012) point out PhD students and other researchers might need training in interdisciplinary skills and crossing organizational borders. Little research on such training programs are to be found in literature, according to Schmidt et al. Townsend et al. (2013) focus on the role of leadership. For interdisciplinarity to thrive at a university, leadership on overall level as well as on the institutional level has to be offered. This kind of support is often missing or inadequate though.

For succeeding with interdisciplinary education programs challenges must be understood and addressed. Several factors, such as students’ previous experience, gender, language and ethnicity, influence the outcome of interdisciplinary research projects (Ryser et al., 2009). Also, the project finances and student-faculty relationships are affecting the outcomes. Duffield et al. (2012) propose following measures for succeeding with collaboration between higher education institutions:

- Create a clearly defined governance model including policies and procedures
- Choose the participants with care
- Arrange face-to-face meetings
- Allocate resources such as time and funding
- Define areas of mutual benefits

Fostering interdisciplinarity could be seen as a socialization process where the faculty engagement and curriculum design are crucial factors for interdisciplinary programs at doctoral level (Holley, 2015). According to the author, a common research laboratory could serve as a key platform for the development of individual and interpersonal skills.

RESULTS AND DISCUSSION

Teachers' perception of interdisciplinary

In the theory chapter, the term interdisciplinary was defined as *"the integration of disciplines as a means to create deepened knowledge of a problem",* focusing three aspects: integration, the creation of deepened knowledge, and on problem solving. The teachers had somewhat different views of interdisciplinary, but most statements could be found within these three aspects, see Table 2.

Table 2. Teachers' perception of interdisciplinarity

The integration aspect	*The creation of deepened knowledge aspect*	*The problem solving aspect*
Most teachers expressed a view where interdisciplinary was created by **joining different disciplines** or as **the activities that takes place between disciplines**. *"learning and working between different disciplines"* It could also be about finding a **communality between disciplines** without losing the essence of the discipline: *"to see what can be seen as a common platform perhaps also keeping the specialties in the different disciplines"* One teacher stressed the approximate **closeness between disciplines,** which affects the possibilities to interact and cooperate between disciplines: *"there are reasons why these disciplines are involved in the specific program"*	This aspect is brought up indirectly when discussing the nature of the interdisciplinary person and the context in which this person acts. The interdisciplinary person could be seen as being able to **apply a broader perspective like a versatile genius**: *"there are some polymaths like da Vinci, they were really interdisciplinary"* These kind of geniuses are not common, but one can find similarities in classical **industrial design project**, where disciplinary knowledge is not enough: *"a good designer has large knowledge of engineering and smaller knowledge about economy"* The interdisciplinary capability is seen as an **outcome of a socialization process**: *"interdisciplinarity is a competence that is being built up"* *"in an operational level confusion, but creative for learners, teachers. It is a scope where teachers become learners. We are learning a lot of this along with the students. It is a journey."* The outcome is not necessarily deepened knowledge for each individual but rather a **synthesis of knowledge within the project team**: *"interdisciplinarity is synthesis - instead of breaking down, you can see the whole"* *"the synthesis occurs in the projects"*	Interdisciplinary was seen as an activity of **problem solving, working together**: *"where you have to solve the task, complex issue with all three disciplines"* *"when persons from different disciplines work together in a course//… you are working on a joint examination assignment"* *"synchronized subject disciplines meet to deliver towards a common goal"* Interdisciplinarity is also connected to **creating new things,** innovations: *"it is the new things that are developing, innovations, are between disciplines"*

One teacher connects disciplinary knowledge with interdisciplinary education. Interdisciplinary education is based on disciplinary knowledge, the teacher claims: *"You need* *to be more disciplinary when working in an interdisciplinary program, especially if you work with industry; what could I contribute with? If I am not useful, I can be replaced!//..//You must be disciplinary in order to contribute in an interdisciplinary context."*

Acquiring disciplinary knowledge takes time, so it is hard to give students disciplinary depth in an interdisciplinary program*: "things that have too high threshold to learn in this short time fits better for disciplinary [learning], things that have a lower threshold fits better for interdisciplinary [learning]"*.

Interdisciplinary is tightly connected with the mode of learning, i.e. project based learning and working in teams. It is hard to be interdisciplinary by yourself, teachers are reasoning in this dialogue:

> *"The interdisciplinary does it not require [interaction] between people? The disciplinary you can do by yourself".*
>
> *"Yes, it is hard to be interdisciplinary by yourself".*
>
> *"At the same time, you may need to reflect on the interdisciplinary yourself"*

The last statement expresses that there are both an interpersonal and a personal aspect in interdisciplinary learning; you create new knowledge in collaboration with others, but you also reflect on your learning individually. Interdisciplinary learning is a process, as any other learning process. The student thus becomes more skilled over time: ***"****There is a big difference when they have done it some time, I really like when they do it the third time – you have different language and different way of keeping up the work."*

Teachers' perceptions of opportunities and challenges

The teachers recognize several challenges with interdisciplinary education. The most obvious challenge is lack of resources or the risk of not having appropriate resources. Resources seen as important are people willing to teach in the program and that have required skills and knowledge, facilities that support interdisciplinary learning, and financial resources. Also recruiting the "right" kind of students was mentioned. Scarcity of resources is partly connected to the current decision channels. When the program was developed it was supported by the rector's office and received dedicated financial support. Today, the program is run as a regular program. Resource decisions and budgets are made on departmental or faculty level, while the program is a cross-faculty initiative. The line managers do not feel responsibility for resource planning, and might hinder personnel to be utilized in the interdisciplinary program, if they are needed in the regular programs of the department. The organizational structure also adds fuzziness to who has decision making power and who handles resources. One current challenge is for instance that the program has not a manager with full decision making. The findings furthermore shows that it is hard to recruit people to interdisciplinary programs as there are no obvious benefits for the teacher, several teachers express, which in turn is connected to the current reward systems. The reward system promotes conducting disciplinary research, and therefore staff are reluctant to join an interdisciplinary program; it puts an additional workload to already high work pressure. Teachers then do not have time enough to engage in the interdisciplinary teaching. In addition, people need to have a positive attitude towards interdisciplinary teaching. The aspect regarding having a positive attitude is connected with intellectual challenges of language and constructs.

The teachers see language as a challenge mainly within the student group. Cultural and language differences were something that was not getting attention in the teachers group from beginning, and which caused problems for both students and teachers. These challenges are reduced during the education though, and the students eventually create a common language. Interdisciplinary is seen as a socialization process where teachers have an important role – they need to teach the students to learn to see things in different ways. The silo mentality of higher education and research is seen as a challenge, and it is hard to show evidence on when learning has taken place, as interdisciplinary knowledge is something different from disciplinary knowledge. Moreover, one teacher reflects on the coordination of different teachers' contribution; teachers deliver what they think a coordinated and holistic interdisciplinary picture of for instance product development, while the students perceive the same as chunks of disciplinary knowledge with no clear connection. The methods of disciplinary teaching and research and those in interdisciplinary contexts also differ. The innovation master is highly built up on project work, open problems and creative innovation processes, which differs from the disciplinary methods. During the focus group sessions however, the teachers do not discuss methods as a challenge. Results in form of quotes related to challenges are summarized in Table 3.

Table 3. Perceived challenges

Intellectual	Language	*"then also the language barrier…"* *"when they present in the beginning you can really hear that they speak their own language"* *"That is an aspect we did not fully understood when we started the program – these cultural aspects need to be taken into consideration"* *"how they from the start speak different languages and then they slowly understand that they talk about the same thing in different way"*
	Construct	*"Students are trained to focus on silo activities"* *"Our way of creating deliveries at universities is disciplinary. Interdisciplinary is rather a way of delivering an education rather than teaching."* *"in the beginning of the program, we as the teachers need to push the ideas to the students that it will be of value to them because they do not understand that."* *"You should also stress the quality of interdisciplinarity – as it takes place everywhere.//…//That is a problem with the program – we do not when the value comes and we cannot see it. When will it come in the student' life? Who knows?"* *"We as teachers think we deliver a coordinated image, but students see individual lectures."* *"We need to be more interactive in our way of communicating our message and knowledge."*
	Method	---

Organisational	Resources	*”find competences”* *” I get really frustrated that people do not have time to help the students. We as a university have not solved all the practical things.”* *“Resource-intensive, if you want to do academic career this takes too much time and is divisive”* *“The university is very driven by the faculties, and personality driven. If it isd going to work over the faculty boundaries, it depends on the people. The people make sure that it happens.”* *“The education should be as a small company, with facilities, class room, and workshops”* *“a physical meeting place”* *“”Everybody says that they lack money and it is complicated…discussion regarding money requirements”*
	Decision channels	*“It is administratively difficult. I get frustrated after I know how easy it should be to solve.”* *“The program would have a leader, but there is someone higher up who decides…”* *“When we developed the education we had a focus that was partly directed by the Rector's Office, then we entered the line organization and then I experience something happening - the focus disappeared and the program became one of all programs”* *“requires leadership, coordination, follow-up, //…//teachers miss it if it is not there”* *“The university's control system - trends in the university world towards disciplinary, being a program manager is an ungrateful task”*
	Reward systems	*”I am involved in disciplinary research - so in my research I have no use of this.”* *“Resource-intensive, if you want to do academic career this takes too much time and is divisive, also one has a publishing requirement”*

While challenges are many and of diverse nature, the opportunities mentioned during the focus group interviews are few. One benefit is seen in the mode of teaching – interdisciplinary education often involves active and student-centered learning where the teacher’s role is rather the one as a facilitator, and where knowledge is created together with students. As one of the teacher states:

> *“the possibility for the teacher is to learn themselves”*

The teaching is seen as a knowledge creation process for students and teachers alike, and some teachers really like the close interaction with the students: *“It is a scope where teachers become learners.” “We learn a lot of this along with the students. It is a journey.” “possibility to follow the students, in different contexts, in two years’ time and see how they develop”*

Some teachers also mention benefits on the institutional level in form of increased reputation and positive impact in the competence acquisition process: *"a good education provides promotion for the university"*, *"we identify the stars that we can employ"*

CONCLUSIONS, IMPLICATIONS AND FUTURE RESEARCH

Introducing interdisciplinary programs into a traditional university structure has to be conducted with caution: being interdisciplinary stresses the faculty members and challenge them to widen their comfort zone. Therefore, it is important to know challenges as well as opportunities that are ahead along the introduction of interdisciplinary programs. The teachers perceive interdisciplinary learning to take place in the project assignments: the projects integrate different disciplines and the students become forced to find ways of effective working, as the project assignment.

The study shows that there are more challenges in relation to opportunities working on an interdisciplinary program. Both intellectual and organizational challenges seem to occur in the studied program. Most tangible are the lack of resources and unclear decision channels. This affects the individual teacher in form of confusion regarding teaching assignments as well as leadership. An interdisciplinary program resembles a matrix organization, while the university is organized as a hierarchal structure. This is one of the reasons behind the apprehended complexity. In addition, the teachers indicated the lack of incentives such as reward systems. Instead, the individual teachers seem to enter the program based on personal interests. As stated by one teacher: *We do not do this for convenience, we are urged to do something good… it is our passion*". The teachers recognize that interdisciplinary learning is different from disciplinary learning, especially from the students' perspective. Students need to learn how to conduct interdisciplinary work, but it is hard to know how to teach and when interdisciplinary learning occurs. The teachers perceive that students become more interdisciplinary along the projects, but they are not sure how this is done.

For the individual teacher there are few incentives to participate in an interdisciplinary program, and working in an interdisciplinary manner is a learning process even for the teachers. This implies that more focus should be given to the education and training in interdisciplinary work for faculty members. Moreover, it is vital for the success of an interdisciplinary program that resources and decision channels are established both in present and in long term. Interdisciplinary programs require structural changes and non-traditional management, as they cross both departmental and faculty borders. Interdisciplinarity is an embryo to a coming subject entering academia, which is in its infancy. Therefore, it becomes important to identify ways to establish interdisciplinarity into the traditional university structure. This constitutes base for further studies.

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BIOGRAPHICAL INFORMATION

Åsa Gustafsson is a senior lecturer at Linnaeus University, Sweden. She received her PhD from Växjö University, Sweden. She is the director for the interdisciplinary master program "Innovations through business, engineering, and design", Linnaeus University, Sweden. Her research interest is in the area of supply chain management with a special interest in the supply chain for soft wood lumber.

Mirka Kans is an associate Professor in Terotechnology at the department of Mechanical Engineering and has been program director for several educational programs since 2004 and forward. She is active in developing the education practices and curriculum according to student centered and active learning concepts (e.g. in form of CDIO), and in close collaboration with industry. Research focus lies within data and information systems for industrial management, and especially on data and IT requirements for maintenance management and how to support maintenance by means of IT to achieve cost-effectiveness.

Corresponding author

Dr. Mirka Kans
Linnaeus University,
Faculty of Technology,
Department of Mechanical Engineering,
Luckligs plats 1,
35195 Växjö, Sweden
mirka.kans@lnu.se

APPENDIX 1

Interview guide

1. How do you define interdisciplinary?

2. Where/how does interdisciplinary take place?

3. How could interdisciplinary be thought?

4. What opportunities and challenges are there for you as a teacher/researcher participating in the program?

5. What does interdisciplinarity mean for you?

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ENGINEERING STUDENTS READY FOR A VUCA WORLD? A DESIGN BASED RESEARCH ON DECISIONSHIP

Siegfried Rouvrais
IMT Atlantique, IRISA, UBL, France

Sophie Gaultier LeBris
Ecole Navale, LEGO, UBL, France

Matthew Stewart
City of Glasgow College, Scotland

ABSTRACT

The need to prepare future-ready graduates is now a major concern for educational programme leaders. But the world is changing at a rapid pace, professional and personal life environments are now more than ever volatile, uncertain, complex, and ambiguous. How can vocational and higher education institutions prepare learners for an unpredictable future? This paper presents an iterative design based research method, initiated in 2015. It explores the links between judgement, decision making skills, and reliability of organisations. Within engineering education and training environments, decision making skills are transversal and can be enriched by a multiplicity and variety of experiential learning situations. As a result of the applied iterative method, decision oriented learning situations can now be categorised in a VUCA rubric of perturbation. It permits educators to continuously reinforce reliability and learner proficiency throughout a curriculum.

KEYWORDS

Learning Outcomes, Decision Making, Transversal Skills, Competencies,
CDIO Standards 2, 8.

INTRODUCTION

The engineering professional activity is to be respectful of standards and industry norms, but is a procedure always directly applicable, whatever the context, e.g. in an emergency or VUCA situation (i.e. Volatile, Uncertain, Complex, and Ambiguous)? In terms of attributes and outcomes, education institutions must prepare their students to embrace changing working practises; but with globalization, are multiple issues still understandable with rationality for the future engineer? The European Network for Accreditation of Engineering Education sets 8 programme outcomes (ENAEE, 2017). One is specific to judgement, where the learning process should enable graduates at Masters degree level to demonstrate the ability to:

- integrate knowledge and handle complexity, to formulate judgements with incomplete or limited information, that include reflecting on social and ethical responsibilities linked to the application of their knowledge and judgement;
- manage complex technical or professional activities or projects that can require new strategic approaches, taking responsibility for decision making.

Strategic approaches involve integrating procedures and rules or developing discernment and exploring new rules. How can we approach and overcome the educational challenges so as to prepare graduates for their future responsibilities? In the curriculum, when and how is it best to develop a student's ability to discern; and make good decisions at right times in VUCA environments?

To deal with complex and multifactorial situations, an adaptation of engineering education is required (Kamp, 2016). To reinforce decision making skills in engineering education, several conceptual and methodological questions remain to be answered. As such, for engineering student's competency development in; and for; VUCA contexts, this paper proposes a Design Based Research (DBR), to analyse; design, evaluate and refine iteratively; the collective behaviour variables of student teams, when facing perturbations in complex and unexpected situations. This DBR was initiated with questions such as: what are the theories of reliability? What are the learner's motivational factors? What are the so called *decisionship* learning outcomes? How do we characterise the VUCAlity of learning situations to continuously reinforce learner proficiency throughout a curriculum?

ITERATIVE DESIGN BASED RESEARCH

Design-based research (DBR) focuses on real educational situations (Anderson & Shattuck, 2012), which are potentially more complex than simulated environments. Inspired by the system engineering principles and agile methods implying clients in iterative cycles, DBR aims to continuously enhance practices (Collins et al., 2004; Mc Kenney & Reeves, 2014). Iterative in essence, the approach is ultimately oriented toward creating, rather than testing, theories. In DBR, regular interactions are in place between researchers, practitioners and trainees. Learners are also responsible for the learnings they experience in the Teaching & Learning Activities (TLAs) enhancement loop.

The DBR takes into account several variables: knowledge, skills and competencies, motivational factors, variables of the learning situations and environmental factors. Based on TLAs continuous improvement, we propose a flexible process of analysis; design; evaluation and revision, as well as expected future theoretical contribution. The research process relies on the following phases (McKenney & Reeves, 2014):

0. <u>Definition</u> of the educational needs and problem (strategies to be used for decision-making processes in VUCA situations with higher reliability);
1. <u>Analysis</u> to identify problem sources (phenomena classes) and formulate learning and environmental operation variables;
2. <u>Design & development</u> of a TLA by researchers, practitioners, and learners, anchored in a theoretical model (TLA concepts, methods, processes and tools);
3. <u>Evaluation</u> of the TLA maturity and efficiency with respect to the variables and problem needs. The TLA is operated in real situations, which are collaborative and participative. Evaluations can be qualitative and quantitative. New

comprehensions are inferred (e.g. emergent concepts). Design principles and rules are formalised;

4. Revision of concepts and TLA methods and tools, based on success and limitations;
5. Reiterate to phase 1.

THEORETICAL MODELS OF RELIABILITY AS A STARTER

The difficulties of decision-making processes in complex or uncertain environments (Klein 1999, Lipshitz et al., 2001) can raise contradictions. The complexity associated with the need for rapid decision-making can lead to information overload and impair the decision-makers' judgment. The multiplicity of procedures, their contradictory aspects, or simply the quantity of procedures to follow in a complex situation can even lead to an inability to decide. The adapted educational answer would be to mobilize heuristics, but this requires learning time, incompatible with an emergency situation. Mathematical approaches of decision making have their limits when confronted with VUCA variables. If a procedure is not always applicable, what strategy of discernment could be adopted?

Some movement on reliability theory consider that individuals are rather a source of error than reliability (Reason, 1990). Perrow (1994) explains that the increased complexity of systems reduces the ability of individuals to understand, predict or prevent potential failures. Errors derive from the fact that "*either there are no procedures provided for the current situation, or the appropriate planned procedures cannot be implemented and constitute a problem of categorisation*" (Mendoça, Webb and Butts, 2010). The stakes of decision-making can be high: an error can have irreversible consequences. But the role that groups and individuals could play in the readjustment decision processes are underestimated. Errors can come from rigid adherence to the established plan as well as from a plan (Klein, 1999). The cumbersome nature of procedures can have an effect on the organizational performance (Brown and Eisenhardt, 1997).

On a theoretical level, our foundations are in line with the models promoted by the Higher Reliability Organisations (HRO) and the Actionist movements. Very close to each other, they seek to identify sources of reliability where decision-maker roles are crucial. HRO movement focuses on the factors that contribute to maintaining reliability, it links observable factors with the absence of disaster by highlighting the ability of individuals to adapt to unforeseen situations and develop a collective mind (Roberts et al., 1994). HROs are strongly characterised by many rules (e.g. nuclear, medical sector). Cognitive saturation can come from an accumulation of written procedures. The Actionist movement (Weick, 2001) deals with the concept of sense making through the theory of enactment, it analyses the way people act in organizations. Weick considers that strict compliance with rules can compromise reliability. In dynamic environments, there is a link between the number of rules to be followed and the level of organisational performance (Davis et al, 2009): too many procedures reduce the level of performance, as well as too few rules.

FIRST DECISIONSHIP ITERATION: AN EXPERIENTIAL COURSE ON RELIABILITY

A skill is only effective once it has been tested and validated when confronted in reality (Le Boterf, 2006). Decision making courses, including TLAs, permit transfer of theoretical models into skills, however, in the real-life VUCA scenarios; the human factors can generate biases and lead to irrational decisions. Learner experiences and skills in discernment, judgement, and decision making should be studied for these new; unexpected situations.

At IMT Atlantique, the TLA context of our DBR is an inter-semester course called INT (2 ECTS), to train engineering students to take decisions and react in unexpected and unpredictable situations. As published in (Rouvrais and Gaultier Le Bris, 2018), this “one week course has some outdoor elements in the sea environment for novices. The real experiential situations are selected to reflect nautical risk scenarios, with varying levels of complexity pressure (including Man Over Board exercises, MOB). Specific decision skills are to be acquired or reinforced, aside risk and priority management, watchfulness, team management with respectful interactions, judgement and responsibility, etc.

Few engineering courses directly address VUCA situations in a real experiential manner (Lewis & Williams, 1994). The engineering program at Reykjavik University runs a two day “Disaster Week”, early in the first semester (Saemundsdottir et al., 2012). Students are to develop an action plan for dealing with an unforeseen event of some complexity, demanding dynamic, instantaneous decision making based on incomplete information. In the fall semester 2017, the scenario was the eruption of a stratovolcano that is actually clearly visible from the University, and it was decided to analyse the VUCA factors specifically as the event unfolded and the students set to work on finding solutions (Audunsson et al, 2018).

The experiential INT course was first designed and implemented in 2015 to allow students to infer and apply procedures and rules in order to face VUCA situations in real environments (educational needs). A real-life approach on INT was conducted among IMT Atlantique students who - as generalist "Grande Ecole" engineering students - need to develop managerial skills enabling them to obtain positions of responsibility. Training focusing on complexity management; can help the future engineer to be more confident, clear-sighted and allow them to identify the main patterns developed during formal training. Work on the development of the decision-making capacity profile of a decision-maker can be an asset in the future.

To start our DBR, we chose to take into account the HRO models and the complexity aspect of Journé (1999). We took into account operational variables, with a flexible revision of the design (Campbell et al., 1966); related to the limits identified in some previous experiments we had from the French Naval Academy (Ecole navale).

Prototype design at IMT Atlantique with the meta-rules concept

The selected theoretical framework allows more methodological robustness, based on previous experimental results we had, following the concept of meta-rules (Gaultier Le Bris, 2014). Davis (1980) defines meta-rules as rules which govern a set of lower-level rules, constituting a framework for which priorities might change. While the decision must be made quickly, based on robust knowledge, the complexity of a situation can lead to a risk of information overload. The decision-maker may face conflicts between the priorities of the procedures to be applied. One possible answer may be to mobilise meta-rules in the context of learning to manage complex situations, offering the advantage for the future decision maker to reprioritise the rules if necessary. They offer the advantage of providing a faster diagnosis of the level of control, with a prompt redefinition of the priorities according to the situation. The results of the meta-rules approach show that they are relevant to improve the level of reliability in a context of uncertainty, urgency and complexity. The meta-rules are adapted to work on the management of complex situations with decision-making difficulties when facing contradictory or unenforceable procedures. They offer encouraging prospects for developing the decision-making capacity of the future decision-maker.

The focus of the INT TLA design phase was initially to examine works relating to the strategy of the rules applicable in complex environments and to evaluate the benefits of meta-rules in VUCA situations. The rules and meta-rules approach proposed in the TLA is progressive and experiential. To observe the impact of meta-rules on reliability and the ability of a learner to decide and maintain a discernment capacity in VUCA situations, the level of complexity of the situations is modified, continuously and/or iteratively through several sequences. In a sequence, the first nautical situation proposed to the students is named Simple Situation (application of rules they inferred) with a low level of complexity (variable 1). The second nautical situation is named Complex Situation (same rules but with a higher level of complexity). After each situation where the student or a team is in a position to act, we measure the level of reliability (variable 2). The application of rules and the use of meta-rules are specifically observed; data is collected with questionnaires and there are debriefings with learners after each sequence.

Qualitative evaluation on motivational factors

First qualitative results (Rouvrais and Gaultier Le Bris, 2018), linked to motivational factors of non-experts and the inference of meta-rules during practical experiences, have shown the benefits of meta-rules rather than rules, prioritising procedures which could contradict or not be applicable in VUCA contexts by non-experts. In this iteration, students were first asked to define meta-rules on their own, in an experiential learning model, where they experienced before conceptualizing, but via several MOB scenarios with enhanced complexity. It would now be pertinent to integrate professional experts into our DBR cycle to formalize the collected meta-rules. It may help to anticipate or reduce cognitive saturation of non-experts. In addition, the learners' qualitative feedback emphasises the interest of working on the capacity of discernment and decision, aside the two variables, i.e. complexity and reliability.

SECOND ITERATION: FORMALIZING LEARNING OUTCOMES AS VARIABLES

In engineering education, the XXIst century sees a shift from scientific and technical knowledge to soft and transversal skills. Skills relate to the “ability to apply knowledge to complete tasks and solve problems, and can be described as cognitive (use of logical, intuitive and creative thinking) and practical (involving manual dexterity and the use of methods, materials, tools and instruments)” (ENAEE/IEA, 2017).

Decision making skills

Inspired by the CDIO syllabus (Crawley et al., 2011) and the ENAEE requirements for graduate engineering profiles (ENAEE, 2017), in this second DBR iteration, five learning outcomes were selected and used for learning activity redesign and student assessments:

- D1: ability to integrate knowledge of the situation context & factors;
- D2: ability to formulate judgements with incomplete or limited information;
- D3: ability to handle the complexity of the situation and during the situation;
- D4: ability to manage complex activities with new approaches, to create new solutions with available resources;
- D5: ability to take responsibility for decision-making.

Quantitative analysis

These decision skills were evaluated quantitatively in 2017 and 2018 on the INT course, offered one time a year. Students were first asked to self-assess on the 5 skills prior to the course. During the experiential TLA, students self-assess several times, individually and collectively, and were formatively assessed by an expert. After each MOB scenario (approx. 7 scenarios in a day), reflective debriefings (Rouvrais, 2013) are in place, in situ. The various sequences provide initial indicators on learning variables to analyse proficiency.

Evaluation showed that the chosen decision skills were to be clarified and normalized for other contexts. A revised analysis to identify new problem sources (phenomena classes) and formulate learning and environmental operation variables is under preparation to explore the links between discernment, judgement, procedures and decision-making. Working sessions with engineering students on discernment and decision skills in VUCA situations, via focus groups, were conducted in the Fall 2017 so as to refine problem sources (phenomena classes) and to reformulate learning environmental operation variables of the DBR. A new analysis is ongoing to refine the learning outcomes referential for a next iteration (Gaultier Le Bris et al., 2017). To refine theories, the researcher and course designer, at national level, attend seminars on discernment & procedure (French Unesco Chair Ingénium network, December 2017) and on complexity (Rochebrune seminar, January 2018). The ongoing DBR will propose a new TLA with its assessment model, in EU institutional contexts for 2019.

ONGOING ITERATION: FORMALIZING A VUCA MODEL FOR CONTEXTUAL LEARNING VARIABLES

The VUCA concepts were to be clarified to link them with learning outcomes and reliability theories. Phenomena classes and complexity experiential variables were to be classified to be linked with reliability.

New design of the T&L offer

For the January 2018 INT session, a VUCA complexity rubric with three levels of magnitude was defined (see Table 1), where an interpersonal dimension was added as it impacts the experiences and reliability of actions. Each sequence of INT are to be positioned in this rubric, by students during the debriefings, and by the experts and practitioners. Each TLA sequence is to enhance the VUCAlity perturbation of the proposed situation to students (project factors, experience resources, etc.) thanks to the previous sequence, e.g. by dynamical perturbation of a data or factor. It relies on a progressive learning cycle, for learner proficiency improvement.

Table 1. The IVUCA perturbation rubric

	Perturbation Rubric of an experiential situation				
Magnitude / variability	***Interpersonal***	***Volatility***	***Uncertainty***	***Complexity***	***Ambiguity***
Weak	Individually or few actors	Low variation of factors, static-ness	Known and formal environment	Simple sources and organization of factors in the environment	Plausible interpretation (a rule or process)
Medium	Small collective or disciplinary team	Predictable change and variance of factors in the environment	Imperfect environment, incomplete and limited information	Several sources and components, high order factors, and low structure	Not obvious interpretation (disambiguation required)
Strong	Interdisciplinary and/or intercultural team	High dynamicity and unpredictability	Unknown environment	Many components and factors, disorganization of factors, no structure	No possible interpretations

The VUCAlity of experienced situations is then to be evaluated as a new set of variables within the DBR, aside the learning outcomes variables (i.e. levels of achievements). Dynamic correlations or interferences between IVUCA rubric elements will be perhaps identified.

DISCUSSION AND INSIGHTS

The world is changing at a rapid pace, and is becoming increasingly VUCA. Now education is about helping students develop a reliable compass and the navigation skills to find their own way through an increasingly uncertain, volatile and ambiguous world (Schleicher, 2015). Embedding decision skills into a curriculum is essential for future engineers to be ready for unforeseen VUCA situations. This paper proposed to analyse the collective behaviours of engineering student teams when facing VUCA situations. The DBR conducted has two main goals for the field of engineering education: (i) to develop innovative TLA solutions to reinforce decision making skills, and (ii) to develop knowledge and open future theoretical contribution. DBR is close to Action Research methods (Järvinnen, 2007). A TLA design in DBR provides concepts, methods, processes and tools transferable to other contexts. The approach presented in this paper, initiated in 2015 with two institutions and since the Fall 2017 thanks to a European project with seven partners, aims at ultimately formalising individual and collective strategies related to the decision-making process in and for VUCA situations, by using innovative and iteratively revised experiential TLAs.

Our findings, derived from TLA problems anchored in real-world settings, demonstrate the relevance of meta-rules in VUCA environments. Decision-making capacities are transversal and can be enriched by a multiplicity and variety of learning situations. Meta-rules offer encouraging prospects for developing the decision-making capacity of the future decision-maker. This approach has a two-fold merit: it defines a framework of understanding in a very fast way for a non-expert; and it is progressive according to the degree of learner's maturity. We see in this approach a way to develop a capacity for discernment when facing many procedures, through training with experiential activities in real situations which the engineer may encounter in a professional context. In addition, learners' feedback from the exercise in real situations highlights work on self-confidence and also the difficulty of optimizing solutions for VUCA situations.

Our works contains limitations: the way to control and measure our variables must be improved, as the prototype design. For transferability, we should also choose other learning contexts for the quantitative analysis. Nevertheless, the flexible and iterative DBR method we used permits to re-formalize decision-making learning outcomes and assessment criteria, in line with the proposed IVUCA rubric. Our research is carefully structured to produce theoretical understanding that can serve the work of others. As theoretical contribution, the approach will allow to propose and make operational a sub-syllabus of decision-making skills for higher and VET education. An assessment rubric of the skills associated with decision-making in VUCA situations will ultimately be inferred and validated in real settings.

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BIOGRAPHICAL INFORMATION

Dr. Sophie Gaultier Le Bris is Senior Lecturer. She has been for 12 years responsible for the academic leadership training at the French Naval Academy. She gives courses in team building (collective mind, higher level of reliability) focusing on the decision-making process of leaders. The aim is to prepare cadets to be resilient whatever situations.

Dr. Siegfried Rouvrais is Associate Professor at the CS Department of IMT Atlantique (formerly Télécom Bretagne). His current scholarly interests are in quality enhancement in line with accreditation requirements, and in methods and processes for Higher Education changes. He co-leads the French TREE research group on Engineering Education Research & Development (http://recherche.telecom-bretagne.eu/tree).

Matthew Stewart is Curriculum Head for Marine Engineering at City of Glasgow College. He is in charge of training Merchant Navy Cadets to achieve their first certificate of competency.

Corresponding author

Dr. Siegfried Rouvrais
IMT Atlantique
Graduate School of Engineering
Technopôle Brest-Iroise, CS 83818
Brest, France

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A DESIGN-BASED VISION ON FUTURE ROLES IN ENGINEERING

Renate Klaassen, Matthijs van Dijk, Roald Hoope

Programme Co-ordinator 4TU Centre for Engineering Education – TU Delft, Professor of Mobility Design, Department of Industrial Design, Lecturer Department of Industrial Design

Daniëlle Ceulemans, Aldert Kamp, Martin Jacobs

Educational Researcher/Designer 4TU CEE- TU Delft, Leader 4TU CEE- TU Delft, Programme Coordinator SEC – TU Delft

Maarten van der Sanden

Associate Professor SEC – TU Delft

A Collaboration between:
Delft University of Technology, the Netherlands
Reframing Studio, the Netherlands
4TU.Centre for Engineering Education

ABSTRACT

In this paper, we present a vision on how engineers can play different roles in future society 2030. First we predicted how society in the Netherlands (in relation to Europe and the rest of the world) is going to develop and how future engineers will behave, act and take their position in this future world. We used the ‘Vision in Design’ methodology to unravel the complexity of future society step-by-step and to understand the diversity of engineer(ing)-behaviour: 260 relevant future conditions for 2030 were derived from 10 interviews with visionaries in society, experts in the field of engineering education and from literature search. Clustering these factors into ten driving forces helped us to discover three independent determining dimensions, defining eight possible engineer-behaviours in 2030. As a result of this rich contextual research, these eight roles are further illustrated with accompanying skills and pathways to support role development. The vision and roles have been developed in co-creation and validated in a series of workshops with a wide variety of people within and beyond academia and within the professional world of engineering.

KEYWORDS

Engineering education, Vision in Design, Engineering Roles, Higher Education, Behaviour, CDIO Standard 1 (Context)

INTRODUCTION

In 2015 a Think Tank was established at TU- Delft, facilitated by the 4TU Centre for Engineering Education (4TU CEE). The Think Tank's main aim was to discover what future engineers should learn during their education to be properly prepared for the future labour market in 2030 (Kamp & Klaassen, 2016). Three main outcomes resulted from this endeavour; **thematic interdisciplinary hubs** as a meeting ground for teachers, learners and researchers and engineering professionals on trending scientific developments besides the regular disciplines. **Building a common language** amongst engineering professionals with different disciplinary backgrounds. Last but certainly not least **different engineering roles** that create more personalised profiles on top of disciplinary knowledge. Engineering roles may serve to a) stimulate personal development of the engineer, b) facilitate teamwork and c) create multiple perspectives via engineering roles, which help to tackle complex problems by means of engineering and technology (Hooimeijer, et.al 2016, IGEM 2017).

The latter outcome on different engineering roles was widely supported and found its way in the TU Delft Vision on Education 2018- 2024. Follow up questions were concerned with, "How to scientifically substantiate these roles or any type of roles for education"? Why do we need roles and are the established roles "THE" roles to work with? And how should these roles be implemented in today's education? Therefore, we have continued this research and reframed the roles via the design engineering research method, called "Vision in Design". This reframing activity resulted in a vision of the future context, future roles engineers can play, possible educational concepts that relate to these roles and illustrations for possible implications of these new insights on higher education.

Thus, 4TU CEE decided to involve "Reframing Studio", a strategic design agency working both in the fields of future business development and future societal change, to:

a) re-explore the potential relevance of engineering roles in education;
b) create a vision on future education which allows for a more diversified approach to embedding engineering roles in Higher Engineering Education and;
c) create a more profound theory that would back up the use of engineering roles as a new route to differentiation in engineering education.

The method used to reframe the future of education and the possible roles engineers can have is called Vision in Product Design, developed in 1995 by Paul Hekkert and Matthijs van Dijk (2011). It is a method that allows for solutions **emerging from** the future, as opposed to **imposing** solutions for current problems, **onto** the future.

The reason 4TU CEE chose for Vision in Design as a viable method to explore the future of higher education is the fact that abduction is at the basis of pragmatic research. Pragmatic research helps to infer the likelihood of certain future developments and results. At the same time pragmatic research does not provide a conclusive direction, but allows for multiple and workable solution paths (Dorst, 2013). The Vision in Design method helps us to identify or design a process towards new meanings of education rather than framing the design solution as the one and only answer (Hekkert & Tromp, 2014). As van den Akker (1999) states; it realises a set of procedural design principles valid for a particular context domain. The outcomes are determined by the level of engagement within the context domain of education, technology and (applied) science.

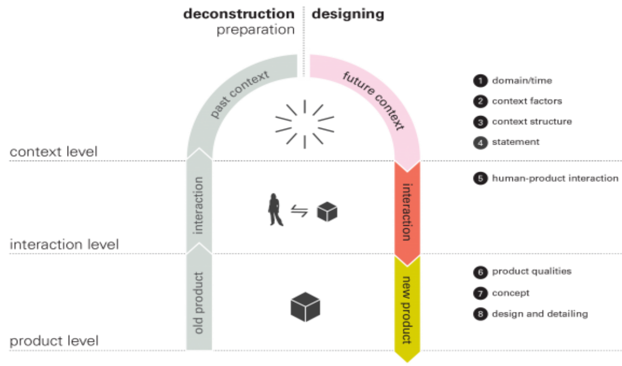

Fig. 1. Vision in Design Process

In Figure 1 above, we find a conceptual representation of the Vision in Design Process. It states that before we start to think about future possibilities we first need to deconstruct the current design for a particular solution. To understand 'the why' behind the 'world of solutions' currently used. It creates a sense of urgency for change and helps to start acting as a responsible organisation within the higher education domain.

Deconstruction

On the left-hand side of Figure 1 we find the deconstruction process. The deconstruction phase consists of 3 steps: understanding the artefact as such (the product level), the "what" , understanding the relationship between an end-use and the artefact (interaction level), the "how" and understanding the conditions that were taken into consideration (the context level), the "why". The deconstruction phase helps us to understand if current policies, services or products (the 'artefact) are still meaningful within the current context, the world of today.

A deconstruction phase is therefore not executed to only asses the current artefact as such, but also to understand how the artefact elicits specific effects on its end-user within the context it has been designed for. It unravels if the artefact elicits the desired effects of the end-user through the interaction and therefor is still of meaning within the current context. Often it is discovered this is not the case.

Designing

In the 2015 Think Tank we already found that a) we needed to educate an engineer as a whole person, who should be able to reach his/her full potential by acknowledging that personal development is part and parcel of education. b) This would require a more specific profile embedded in the current engineering programmes, including coherent tracks across the university and acceptable to accreditation bodies. Finally, it should create added value for future society.

The reframed and leading question for this consecutive research is: "What roles of the engineer could be of meaning in a future society?"

The Vision in Design method initially explores a future context (2030) related to a specific domain (in this case the domain of technology, education and society) by first collecting the building bricks, you could say the conditions, a future world is conceived of. These factors are distilled from interviews with key game changers in the field, literature research and reports that deal with the future of engineering education. All these different techniques lead to an understanding of which specific type of factors need to be taken into account. There are two time-dependent factors: the ‘developments’ (such as demographic changes over time) and ‘trends’ (behavioural change over time) and two time-independent ones, the ‘principles’ (laws of nature, such as the theories on emotional response) and states (cultural phenomena that are not in principle stable, but stable within the scope we are doing research for). Successively, each of these labelled factors are categorized by a design team into clusters, the driving forces of the future context. An underlying pattern existing out of three dimensions describe the relationships between all these ten driving forces and give direction to potential future roles engineers can have in the future world. Future dimensions thus typically define the design space from which the design solution should emerge.

In this study, we’ll share the initial steps results in a vision for higher education and the validation of an initial design solution for Higher Education (Curricula.)

Educating future engineers

How can we equip future engineers with the skills they need to play their role?

In the beginning of this design research seven people in the Higher Education Field have been interviewed. These were researchers, policy makers of the Rathenau institute, TU Delft, M.I.T., Leiden University, Utrecht University, Institute for Social Research and Plant engineering and Design. Many more books on the future of Higher Education, Technological Developments have been consulted. Resulting in over 260 future context factors. Through a process of expert discussions and sorting, these were clustered into ten driving forces and reduced to a framework of three dimensions, leading to eight different roles an engineer can have within future society. A future engineer can also give expression to a combination of roles at one moment in time or shift roles depending on the situation or context encountered at a certain moment. This framework has been presented in several workshops, in which a total of 32 people attended to validate and discuss the framework as established. In the following paragraphs, we’ll share a summary of the framework, the possible engineering roles and the validation results from the workshop.

Ten Driving Forces, Three Clusters in detail

The framework consists of three major dimensions: engagement with technology, trust and collaboration predicting the way engineers may interact with work, and development cycles (of products, systems, services, etc). Each of these dimensions is defined by the ten driving forces which have emerged from the 260 future context factors and will be described and visualised below.

1. Engineers will increasingly find purpose in salient societal challenges
2. Meritocratic engineering culture and education as 'rite de passage'
3. Science is no longer the only source of truth
4. Engineering talent will hop to and from new urban hubs
5. Meaning-making as the backbone for digital and analog growth
6. Technology will smooth out people's fear of technological change
7. The future engineer is intrigued by things, and by the people in them
8. People will have a life-long entrepreneurial mind-set
9. Collaboration will be more open, interdisciplinary and mediated by 'black-box' systems
10. 'Learning' will mean staying in tune with the next big things

Figure 2. Ten Driving Forces for Engineering Education

Engagement of future engineers in the quest for technological solutions are driven by societal **challenges**, like the grand engineering challenges or a deep desire to explore and contribute to the understanding of **technological phenomena**. Engineers will be faced with the fact that graduating as a "rite de passage" is opening doors to a future career and is necessary to grow. At the same time the results of scientific endeavours are no longer taken at face value and not necessarily accepted as a source for "the best" technological solution (driving forces, 1, 2, 3 and 7).

Trust and Collaboration is the second dimension showing the interaction at an **interpersonal** level stimulating small disruptive innovations at a level where systems do not yet exist. Opposite the interpersonal there is engagement with incremental (technological) improvement as part of building systems to ever better technological results. Technological hubs like Silicon Valley or increasingly Singapore and other Asian hotspots are bringing together innovative kick-starter's and front runners in tech (Aalto University, 2017). To be on the edge of technological development the engineer needs to go where tech is big and happening and have trust in interpersonal relationships. On the other hand, we are all part or will become a part of the **system** through permanent dataflow. Institutes and multinationals will drive for more systemic change and engage different types of engineers to master, alter and steer the dataflow systems. Although technological change is accelerating, it still needs a story. Meaning making as a part of trust and collaboration with the system or with individuals will still be at the centre stage for technological acceptance and in the domain of engineering education (driving forces 8, 4,5, 9).

Development Cycles are the last dimension driving the engineering and learning behaviour now and in the future. Development cycles are going **faster** all the time requiring swift entrepreneurial behaviour and forcing people to grasp every other opportunity. Moving on to the next big thing stimulates and pushes lifelong and very personalised learning for engineers in every walk of life. Contrary to the fast, we find **slow** development cycles. These process of long-term technological advances, which require long and dedicated attention to development, implementation and systems adaptation, taking into account governance, legal, policy issues and certainly cultural norms and values.

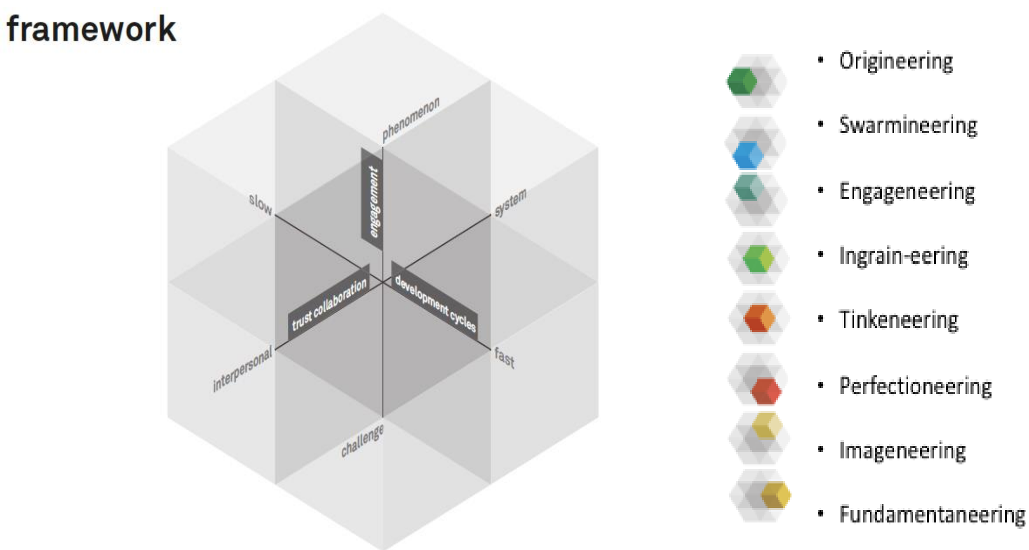

Figure 3. Framework for the Future of Engineering Education

The framework shows the three driving dimensions that are likely to determine engineering behaviour. At the end of each axis one finds the future determinants: Challenge versus Phenomenon, Interpersonal versus System, Fast versus Slow. Each combination of determinants give an insight in a possible role engineers can play in the future, i.e. in the future behaviour and underlying concerns of the engineer of the future. Each possible role can be addressed through the realisation of an educational path, and through specific life experiences along the way. The model frames the diversity of roles engineers can have, a diversity of roles that is appropriate within future society. The type of engagement with the future 'world' will determine the skills needed. Of course these roles will evolve over time with the ever-changing context taken into account. Some of the behaviours have already taken root in society. Others are yet to emerge and some are still to be detected. Each of these insights into future roles of engineers in society will be elaborately described in the forthcoming book and find their origins in the engineering profession.

Challenge x Interpersonal x Fast

1. origineering
Seizing a societal opportunity to bring people together or work together creating value and impact on the short-term

like a serial entrepreneur
skills/attributes: initiative and self-direction; courage: resilience; business sense/economic realism; the ability to apply theory in practice; market intelligence

Phenomenon x Interpersonal x Fast
5. tinkineering
Identifying with the 'state-of-the-art' in several specific fields of interests and staying up-to-date through like-minded people with a similar strong interests. Finding ways to apply the latest insights/ discoveries/technologies in real-world settings;

like an amateur professional
skills/attributes: trend awareness; adaptability; self-direction; tech-savviness; practical ingenuity

Figure 4. Two examples of Engineering Roles

WORKSHOPS

The validation workshops questioned participants (n=32) from the engineering field and in academia on the following aspects:

- Resonance: Do you recognise these behaviours in your field of work and do you see these behaviours becoming more significant in your field (scored on a Likert scale 1 to 7 from low neutral to high.
- Assessment: at the end of each session participants were questioned on:
  - the relevance: of the frameworks for the field of engineering, (Likert scale 1-7, not at all relevant to extremely relevant
  - the appropriateness: Is it acceptable to use this framework on an ethical level. (Likert scale 1-7, not at all appropriate, to extremely appropriate)
  - The strategic value: can it be used as a tool for educational institutes for strategic planning (Likert scale 1-7, low value to high value)
  - The inspirational value: is the framework an inspiration to developing new educational systems (Likert scale 1-7, not at all inspirational to extremely inspirational)

  Questions were again scored on a scale from 1-7 and participants were invited to give comments.

Note that the questionnaire as such is not tested on reliability. The questionnaire was rather a departure point for discussion and not consistently scored. The sample groups are small and of diverse nature, not allowing for statistical violence. The scoring is therefore, reported as descriptive results and discussed for each group, including the summarised qualitative comments. Sometimes part of the ongoing discussions has been included. As it is a design-based approach, each consultation round offered insights for incremental improvements (van den Akker, 1999).

RESULTS

The workshop results are discussed in the following sequence. First the sample group is briefly described. Then the resonance in terms of presence of certain behaviours on a dimension and the emergent behaviours are summarised. Successively, the numerical results (descriptive frequencies) of the workshops are presented in the table and aggregated at the end of the table (total). After the table a summary is presented of the comments made with respect to each variable: relevance, appropriateness, strategic value and inspiration. Each section closes of with a conclusion on the commentaries of the workshops.

	Emerging roles	Workshop 1 M =	Workshop 2 M=	Workshop 3 M =
1	origineering	5.8	5.8	5.9
2	swarmeneering		5.9	
3	engagineering			5.1
4	Ingrain- eering		5.1	
5	tinkeneering	6.4	5.0	5.2
6	perfectioneering	5.8	5.7	
7	Imagineering			5.4
8	fundamentaneering	5.7	5.0	5.0

In workshop 1. at the Dutch Design Week (n= 12), workshop 2. at the Teaching Lab and workshop (n= 7) 3. at 'Lijm en Cultuur' (n=13) different stakeholders attended, ranging from designers, artificial intelligence experts or and experts in the field of education leaders. Most of them assessed origineering, tinkeneering and fundamentaneering as emerging roles. Two of the roles are described in Fig. 4. Fundamentaneering being Phenomon, Slow and System driven is at the other end of the dimension. Participants felt origineering was strongly present already.

Table 1. Descriptive Frequencies of Variables on Likert Scale 1 to 7

Workshop 1	N=	1	2	3	4 (neutral)	5	6	7 (extremely relevant)
Relevance	10				1	1	8	
Appropriateness	10			1	3	2 (1= 5.5)	3	1
Strategic Value	10				1	1 (4.5)	4	4
Inspiration	13				1	5 (1 = 5.5)	7	
Workshop 2	N=	1	2	3	4 (neutral)	5	6	7 (extremely relevant)
Relevance	4					1	3	
Appropriateness	8			1	4		2	1
Strategic Value	10				2	5	2	1
Inspiration	6		1			1	4	
Workshop 3	N=	1	2	3	4 (neutral)	5	6	7 (extremely relevant)
Relevance	13				3	3	5	2
Appropriateness	16			3	4	4	4	1
Strategic Value	13		1		3	3	4	2
Inspiration	12			1		2	5	4
Total	N=	1	2	3	4 (neutral)	5	6	7 (extremely relevant)
Relevance	27				4	5	16	2
Appropriateness	34			5	11	6	9	3
Strategic Value	33		1		6	9	10	7
Inspiration	32		1	1		8	16	4

- The numbers in this table indicate the Likert scale scores from 1 to 7 in the columns and in the rows the descriptive frequencies scored on these scales for a particular variable. So in workshop 1. 10 people scored the variable relevance, of which one person on scale 4, one person on 5 and eight people scored 6.

Relevance

With the question "Is the framework relevant for Engineering Education? We investigated whether the model on the diversity of roles engineers can have in the future could be used to (re)design engineering education and whether it was relevant for the engineering field. The expertise of the workshop participants was crucial, as they had to relate their feedback to their own field of practice. Each field of practice was different for each workshop sample.

W.1. With respect to the question "is this framework **relevant** for the engineering field? ", 8 out 10 answers, scored this question with a 6. This means the framework is very relevant for the engineering field. Remarks amongst others were; "*A very useful context analysis translated to a practical 3D framework". "A Framework to dive deeper into engineering and thinking about the future of the engineer*". "*It allows for roles to function as themes on a spectrum in education*". "*Engineering is a process of compaction, choosing out of endless possibilities and should be allowed to be debated and grow*."
W.2 In workshop two, the participants felt **relevance** was hard to assess as 1.) the model lacks future scenarios and 2) it is difficult to gauge what the framework should be relevant for.

It may also have been caused by the un-clarity about the perspective commenters had to take to address this framework.

W.3 Seven out of 13 have found the framework **relevant** in workshop 3, especially at the contextual level the dimensions provides a point of departure "*to help student think of what they want to become*" or use it as "*a growth model*" to discuss student ambitions. At the same time, it is stated that the framework describes situations, in terms of norms and values, which need further validation in real life situations. This is tied into the question "*How many of these behaviours/interactions are already signalled in the world of companies?*" Finally, it is questioned whether the dimension "source of engagement" is really so interesting and if it should not be "Challenge" only instead of challenge vs phenomenon.

Overall, 50% felt the framework was very to extremely relevant. Which we interpret as having a framework which contextualises the engineering world of 2030 in a representative way. It warrants a further exploration of concept designs for engineering education programmes.

Appropriateness

The appropriateness questioned the ethical aspects of the framework. "Is it responsible to use this framework?" and "does it constructively affect the engineering field, the students and/or education?".

W.1. The **appropriateness** was more of a discussion issue as opposed to the relevance, with varying scores from 3 to 7. In the discussion participants questioned the appropriateness of the framework for a non-Dutch context, non- white male academics and women. Beside the cultural aspect they questioned, the lack of taking the 4th Industrial Revolution into account. It was questioned whether AI/Robotics take over large parts of our future engineering jobs and part of these roles. Furthermore, they felt the risk of putting people into a pigeonholes is latent.

W.2 In the second workshop it was deliberated whether the framework would incite demand driven engineering education, in which only the educational scientists or industrial view would count. The belief is that education should be curiosity driven and not market driven. Despite the participants fears they also felt *"It is good to take social engineering, society and environment, as variables beyond technology, into account for any curriculum"*.

The response of the Artificial/Robotics specialists was as follows.

AI: With respect to AI/robotics it is stated that the merging and utilisation of AI technologies and models in robotics, such as artificial intelligent robotics and ethics will be a major dimension. It requires deep knowledge of artificial general intelligence, machine learning, deep learning, fuzzy ethics and legal education of(social) intelligent agents design and developments, programming and automatic control (control theory). It is likely that people focus even more on a specific knowledge area, although you do have a general knowledge about the other engineering roles".

W.3 The group was a little more divided about the **appropriateness** of the model. Most felt there was a risk in there to pigeon-hole the students. It was more a framework for talent development, discussion and an open choice for students to work on these talents. As such it was considered appropriate to implement it in education as a developmental direction.

Although there were many questions with regard to appropriateness, 50% still scored this as being moderately to extremely relevant. We expect that with a slight redesign, adapting to some of the criticism, the framework will gain in appropriateness for the engineering domain.

Strategic Value

Strategic value addresses whether the framework is useful for planning higher education programmes. "Does the framework support decision making processes with respect to the future of engineering in higher education?"

W.1. In workshop 1, the majority considered the framework as a valuable **strategic** planning tool for higher education (in particular in the Netherlands and possibly Western Europe). "*It helps to think strategically and yet become practical*". "*It provides insight into necessary skills and it is a good platform to start a conversation on new (piloting) programme*s."
W.2 The **strategic value** is that it allows programmes to push engineering education into a certain direction, yet it all depends on the acceptance level, and the open mindedness of the institution to new ways of learning. It should incite discussion on educational settings, discussion which are necessary to practice these or any role in engineering.
W.3 **In workshop 3,** 9 out of 13 participants were positive about the **strategic value**, yet only 6 saw a latent potential in the framework to rethink engineering education. More as in "*it is always relevant to think about renewal education, it helps critical reflection, but it could also be any other model".* The explanation ranges from, "*everything should be crystal clear to be able to work with the framework*", to "*these can be potential driving values for repositioning*", "*if the community is open to drastic change*".
Across the board around 75% considered the framework to have strategic value for higher education to start a discussion or to rethink engineering. Yet the participants feel there are a number of obstacles that need to be addressed . These are 1) the risk of creating demand-driven education 2) resistance to (radical) change of organisation and staff and 3) a lack of open-mindedness towards new ways of learning. Finally, participants questioned "*why we should use this model and not any other for that matter*". Which means the value proposition needs additional attention in follow up activities.

Inspiration

Inspiration is the last variable questioned. "*Is the framework a source of inspiration to create "new" types of engineering education"?*

W.1. Most participants in this workshop felt it was an **inspirational tool** to elaborate on the possible higher education programmes for the future. "*it is interesting for young people to know which role they play in the engineering world"*. "*It is a way to structure the future in other then just words and predictions*". "*it is helpful to making choices in future careers of current engineers, nice framework*" and "*grip in a complex world*" were some of the remarks made.
W.2. "*It is an **inspirational** toolbox that if used every 2 to 3 years will improve insight*". "*It offers a whole new framework to think about the form and content of education/project work*". "*It does challenge us to give new meaning to creativity"*
W.3 Most of the people in this workshop were convinced of its **inspirational** value. The participants stated, "*it is a toolbox, to look differently at education", "to explore new options", "to create new innovative concepts of courses", and "it opens up new venue's*". The dimension are felt to be complete, yet give a context to move around in.

Overall 85% of the workshop participants felt the framework offered an inspirational tool or toolbox to think about and develop engineering education for the immediate to long-term future.

DISCUSSIONS AND CONCLUSIONS

Most of the participants with whom we have discussed the framework felt it is relevant, of strategic value to higher education and the engineering field and certainly an inspirational tool to personalise and differentiate engineering education for the “near” and far future (2030). The framework is relevant as the dimensions are considered representative of the emerging future context and are partly recognised as being already present. The strategic value is that the framework is stimulating a more diverse approach to higher engineering education programmes and challenges policy makers, programme directors and others involved in curriculum design to think differently about the future engineering education programmes. This approach allows for diversification and adaptation to personalised learning for both students and alumni. The added value for society is that we will be offering newly developed education programmes, matching the future societal and emerging context of 2030. The value driven behavioural perspectives allow for agile adaptation to the world to come.

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BIOGRAPHICAL INFORMATION

Renate Klaassen is Programme Co-ordinator and Researcher for the 4TU Centre for Engineering Education at Delft University of Technology. Design thinker and facilitator of the 2015 Think Tank at TU Delft established to explore the Future of Higher Engineering Education. Researcher and Educational Consultant into Higher Engineering Education, supporting a team who research, realise innovation sessions and advise on Engineering Roles of the future, Virtual Reality Systems, Interdisciplinary education. Here personal academic research field is Content and Language Integrated Learning.

Matthijs van Dijk Prof. Ir., holds two part time chairs; one as Professor of ‘Applied Design' at TU Delft and one as Professor of 'Strategic Design' at NTNU in Trondheim. He is also the founding partner of design consultancy Reframing Studio which advises organisations on how to maintain their competitive or societal position by creating meaningful new products, services and policies. Matthijs is a highly regarded thinker on innovation methods and in that capacity he is frequently asked as a speaker and member of juries and committees. He co-authored a book about the innovation method he developed at TU Delft: Vision in Design, a guidebook for innovators (Bis Publishers).

Roald Hoope is designer and insight specialist at design consultancy Reframing Studio where he develops visions on future consumer behaviour and translates these into concepts for new products, services and policies. He coaches design students at the TU Delft who are learning to apply the Vision in Design innovation method and he shares his expertise with management professionals as a trainer at Reframing Academy, Reframing Studio's own training institute.

Daniëlle Ceulemans Educational research and designer at the 4TU Centre for Engineering Education of Delft University of Technology. Expertise in human centred design and interaction design. Working on multiple design-based research projects and development of (online) educational interventions.

Aldert Kamp is the Director of Education for TU Delft Faculty of Aerospace Engineering and Co-director of the CDIO-initiative. He is deeply involved in the rethinking of higher engineering education with a horizon of 2030. He is the author of the report “Engineering Education in a Rapidly Changing World – Rethinking the Vision for Higher Engineering Education” and fervent blogger about “Adapting Engineering Education to Change”.

Martin Jacobs is co-ordinator of the teacher education department of TU Delft.

Maarten van der Sanden is an Associate Professor of Communication Design for Innovation at TU Delft, Faculty of Applied Sciences, dept. of Science Education & Communication. His research is on the design of decision support tools for professionals making decisions upon effective collaboration processes in social networks of innovation. He teaches communication design for innovation in which engineering students learn how to intertwine technical innovations with its social environments.

Corresponding author

Dr. R.G. Klaassen
Delft University of Technology
Jaffalaan 9a
2828 RD Delft/ Netherlands
r.g.klaassen@tudelft.nl
00 31 (0)15 2788393

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FLUID MECHANICS PROJECT-BASED LEARNING KITS: AN ANALYSIS OF IMPLEMENTATION RESULTS IN A BLENDED CLASSROOM

Alexandra Meikleham, Ron Hugo, Robert Brennan

Department of Mechanical and Manufacturing Engineering, University of Calgary

ABSTRACT

Fluid Mechanics is a foundational course in civil, chemical, and mechanical engineering that is often offered as a combination of lectures, tutorials, and laboratories. In the laboratories, students typically perform experiments using commercial flow benches, following scripted laboratory procedures to conduct experiments. Without a detailed understanding for how these experiments are designed or operate, students often rely on laboratory reports written by students from previous years to guide their analysis and documentation process. From the Bloom's Taxonomy cognitive domain perspective, this represents a lost learning opportunity as analysis is one of the highest levels of knowledge activation that students can experience in a foundational course like Fluid Mechanics. The work reported here seeks to address this lost learning opportunity by increasing active student engagement using inquiry-based learning. In the Summer of 2017, 61 students participated in a flipped-delivery Fluid Mechanics course and conducted five experiments using custom-designed project-based learning kits. The benefits of adopting a project-based approach to learning are numerous, but appear specifically promising in the areas of self-efficacy and professional skills development. Through this approach, students become co-creators of their learning journey rather than passive observers using traditional "black box" commercial flow benches. This paper examines student performance and self-assessed professional skills development through quantitative and qualitative analysis of student results on a variety of assessments and surveys measuring professional skills development. Paired t-tests and hierarchical modelling were used to conduct statistical analyses of a variety of demographic factors influencing student performance on assessment. A qualitative reflection of these results is also conducted. Findings indicate that students reported statistically significant growth in most graduate attributes on two different surveys. Technically-focused attributes (1,2,3,5) ranked highest in terms of growth on both surveys, while attributes 9, 11, and 12, impact of technology on society and the environment, economics and project management, and lifelong learning also saw large improvements. Fourth year students performed significantly worse than their counterparts on the project-based laboratories, likely reflecting a lack of motivation associated with taking a second or third year course later on in their academic careers.

KEYWORDS

PjBL, PBL, Student-centered learning, CDIO approach, Blended learning,
Standards: 2, 3, 5, 7, 8

INTRODUCTION

Educators, employers and regulators have spent a great deal of time creating pedagogies, frameworks, and policies in an effort to close the professional skills gap in engineering graduates (Crawley et al., 2014). In Canada, the Canadian Engineering Accreditation Board (CEAB) created a list of graduate attributes which act as a vetted set of desirable characteristics for engineering graduates. Of the twelve attributes, seven are considered to be professional in nature; the list with professional skills highlighted is presented in Table 1.

Table 1. CEAB Graduate Attributes (Canadian Engineering Accreditation Board Accreditation Criteria and Procedures, 2017)

Graduate Attribute	
1 – Knowledge base for engineering	7 – Communication skills
2 – Problem Analysis	8 – Professionalism
3 – Investigation	9 – Impact of Engineering on Society and Environment
4 – Design	10 – Ethics and Equity
5 – Use of Engineering Tools	11 – Economics and Project Management
6 – Individual and Team work	12 – Lifelong learning

Previous work has demonstrated how these twelve attributes map directly to the CDIO syllabus, indicating that Canadian regulators are closely in alignment with international initiatives in their effort to develop well-rounded engineers (Cloutier, Hugo, & Sellens, 2012). While there appears to be broad consensus on the importance of professional skills in the engineering curriculum, there is still a great deal of work to be done on establishing the best ways to achieve this goal. Project-based learning offers promise in the enhancement of professional skills in engineering education (Crawley et al., 2014a). A brief search of the terms “project-based learning”, “engineering”, and “professional” in the academic database Scopus will return results from 1996 onwards, with publications increasing in frequency every year to present. These trends indicate that researchers are increasingly interested in the relationship between these topics.

Project-based learning appears to be a promising approach for the development of professional skills as it is inherently student-centered. By emphasizing knowledge co-creation rather than memorization, project-based learning requires that students, peers and instructors engage in a dialogue that more closely approximates real-world experiences than the traditional lecture approach. Project-based learning appears to naturally facilitate channels of informal feedback which can support the practice of formative assessment and self-regulated learning (Butler & Winne, 1995). Many Canadian schools offer project-type courses for design-oriented classes, for example, in the form of a final-year capstone project. Less popular, however, are project-based deliveries in technical, core engineering courses. An explanation for this may be that core engineering courses center around “declarative”-type knowledge (Ambrose, 2010). Mastering technical material for many students can be difficult enough, with students spending the majority of their effort remembering or understanding, the first two cognitive classifications in the revised version of Bloom's Taxonomy (Anderson, Krathwohl, & Bloom, 2001). As many of these courses function as pre-requisites and form the basis of engineering fundamentals, it can be challenging to meaningfully integrate professional skills development into an already tight technical curriculum.

Blended learning and PjBL appear to address some gaps but it is important to document and better understand its benefits and drawbacks. As a result this study was designed to better understand what the pitfalls are and illuminate key findings that may enhance the way that others engage with it in the future. In the next section we discuss research questions and then follow with the methodology, results, discussion and conclusions.

RESEARCH QUESTIONS

This paper will discuss the experience of implementing project-based learning in a technical fluid mechanics undergraduate course. A description of the course setup, motivation, and findings are presented. The questions being investigated in this paper are:

- Can project-based learning in a technical course significantly increase self-reported professional skills as measured by two sets of paired surveys?
- What are the factors in the context of technical project-based learning that influence professional skills development?
- Is there a student demographic that performed significantly better or worse on assessment types in this particular class?

Findings from this experience are shared here to encourage dialogue on project-based learning practices. Locally, further findings from this research will be used to influence continuous improvement efforts within the authors' university.

METHOD

To answer the research questions, a blended, project-based delivery course was created and offered to 61 University of Calgary students in July and August 2017. As the course was offered in a blended delivery format, all lectures were made into videos curated into modules on a free and open YouTube channel. All links to the open videos were placed on the online learning management system, D2L. A more detailed description of the course activities and the methods of analysis follows.

Course Design

Learning Activities

The lab activities were designed to reinforce technical learning outcomes covered in YouTube video lectures and reviewed in active learning tutorials. Students were also given access to additional problem sets which were not graded but promoted self-directed mastery of technical concepts. Weekly quizzes were used to validate uptake of technical learning outcomes from the sum of the previous week's activities. At least one quarter of weekly quiz questions were based off technical learning outcomes from the active learning laboratories, with additional questions geared towards concepts from the online lectures. Active learning laboratories were used to scaffold professional skills development with technical learning, and weekly quizzes served as checkpoints to validate synthesis of technical concepts. Table 2 summarizes the course activities and how each were assessed.

Table 2. Course Activities and Assessment Items

Course Activities	Type of Outcome	Assessed by
YouTube Lectures	Technical	Cornell Notes, Quizzes, Final Exam
Active Tutorials	Technical and Professional	Clicker responses, self- and peer- formative assessment
Active Learning Laboratory (Design-Build, Experiment)	Technical and Professional	Report, Poster or system map, Quizzes and Exam
Problem Sets	Technical	Self-assessment (no grade)
Cornell Notes	Technical	Cornell Notes Rubric

Figure 1 depicts the constructive alignment of learning outcomes and activities conducted in this course.

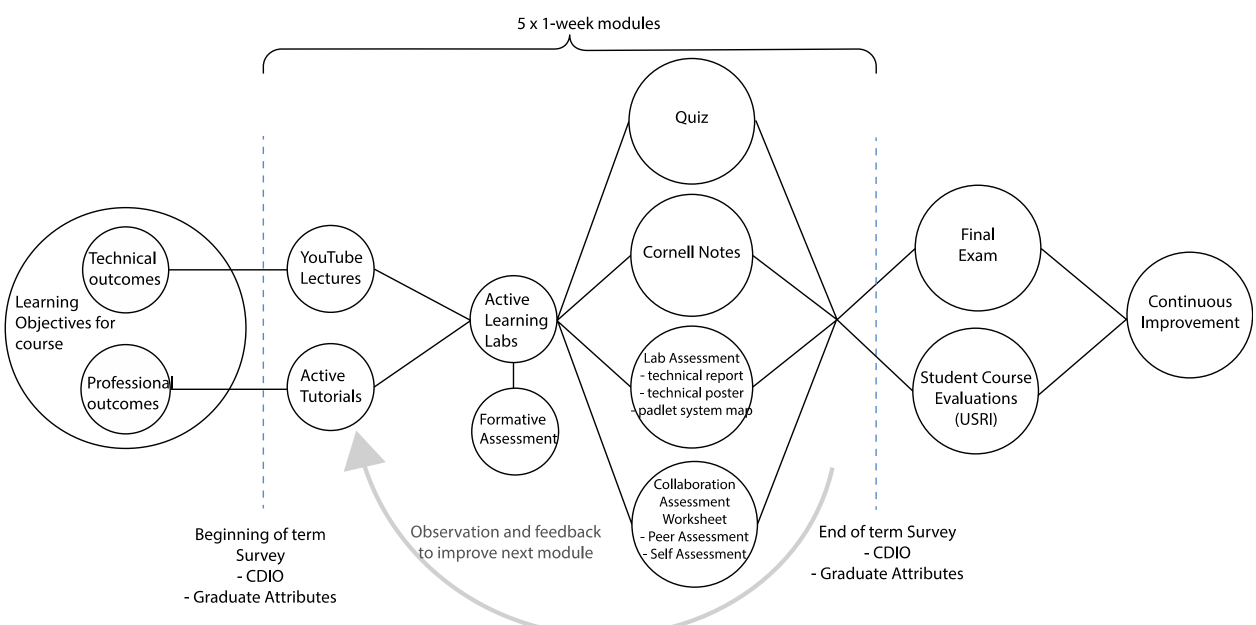

Figure 1. Visualization of constructive alignment of outcomes, activities and assessment of the course.

The course was run in five modules which covered technical and professional learning, with some aspects scaffolded from week to week. It is important to note that while lab assessment appeared to be independent of exams, there was overlap between the assessments in terms of the learning outcomes that were assessed.

Active Learning Labs

Five laboratories were offered using project-based delivery, a more detailed description of the laboratories can be found in the Appendix. The major themes for each of the five experiments were: calibration of a flowmeter and measuring volumetric flow rates, hydrostatic pressure, momentum transfer and nozzle design, pump performance and dimensional analysis, and head loss in a pipe network. For each lab, students were provided a set of objectives and high-level instructions that would guide discovery. This was meant to encourage self-regulated learning within a technical course which has historically been taught using step-by-step scripted laboratory experiments performed on commercial laboratory bench systems. Student teams were required to design, build and operate their own experimental apparatuses using a standardized kit of supplies that was assembled by the authors. For example, instructions on pump and power supply setup were provided, however explicit dimensions for pipe assemblies were not. This resulted in 15 (the number of teams in the class) unique setups for each of the five labs, all constructed from the same standard set of materials and basic instructions. Students were asked to formulate their own hypotheses and base their experimental approach and analysis in theory, while instructors were available to provide feedback on this process. The supplies included ½” PVC piping and fittings, pumps and power supplies and a number of experiment-specific items, such as calipers and balloons.

Figure 2. Standardized kit and additional lab-specific materials.

Active Learning Lab Assessment

Each week lab teams submitted a summary of the lab and their results for assessment. A technical memo was assigned for lab 1 and 3, while a technical poster was assigned for lab 2 and 4. Lab 5, head loss in pipes was designed to scaffold on previous experiments, particularly experiment 1, therefore students were asked to create a system map on the online tool Padlet.com. This tool was utilized because it allows collaborative work (more than one student can work on the application at the same time), and can store text, images, videos and voice memos.

Exams

One quiz was administered each week, for a total of five quizzes throughout the summer semester. Students were given one hour to complete the quiz, and directly after finishing, were placed in teams according to their rank on the previous exam. The grouping for the first exam was done randomly. Each team was assigned a top, middle, and low-ranking student. The teams were then given one blank copy of the same exam and had 30 minutes to complete it together. This was to encourage student dialogue and formative assessment practice among peers. A final summative exam was administered at the end of the term, and students did not repeat the final exam in teams. The five quizzes comprised 40% and the final exam 25% of the semester mark.

Peer and Self-Assessment

At the end of each lab module (after lab reports were submitted) students were asked to fill out assessments of their team members. A copy of the peer assessment form can be found in the Appendix. Outcomes assessed on the form were: participation, leadership, listening, feedback, co-operation, and time management. Students were also required to self-evaluate on these skills. Peer and self-assessment comprised 10% of the students' course mark. Formal and informal discussions on the importance of professional skills development were conducted throughout the semester usually in the active learning tutorials.

Cornell Notes

One half-page of Cornell Notes per lecture video (5-10 minutes) were implemented to encourage early student engagement with the material. This was initiated to mitigate a finding from when the same course was offered in 2015 that video watch minutes peaked the evening before quizzes.

Data Collection

The bulk of this paper will concentrate on the statistical analysis of the results from survey and assessment data gathered in this class, further quantitative and qualitative analysis are presented in a companion paper, Meikleham et al. (2018).

Graduate Attributes Survey

A survey comprised of 38 questions was administered in the first and last lectures of the semester. Students were asked to identify on a scale of 0-1: "How confident are you in your current ability to…?" A response of "0" indicated having no confidence and "1" indicated having total confidence, with responses distributed in 0.25 increments between these two values. A detailed description of the survey and similar analysis on responses from a different group of students can be found in Brennan & Hugo (2016).

CDIO Survey

The CDIO Syllabus at the third level of detail (Crawley et al., 2014b) was used as a survey to verify self-reported competencies on each syllabus item and was also administered at the first and last lecture of the semester. The students ranked their abilities with respect to the syllabus from 0-1 according to the following scale: "0 - To have experienced or been exposed to", "0.25 - to be able to participate in and contribute to", "0.5 - to be able to understand and explain", "0.75 - to be skilled in the practice or implementation of", and "1 - to be able to lead or innovate in". These questions loosely translate to Bloom's taxonomy increasing from Remember (a rating of 0), to Understand, Apply, Analyse, Evaluate, and ending with Create (a rating of 1) (Anderson et al., 2001).

Data Analysis

Statistical testing including general and hierarchical linear modelling and paired t-tests were used to investigate factors related to student performance on assessment and two professional skills surveys, described below. This was to support a holistic discussion on our experiences in project-based learning. The statistics provide valuable insights to this discussion but are only one part of a much bigger picture. These methods are mainly used to help support the qualitative discussion of the statistically significant factors in our experience offering project-based learning. A drawback to this approach is that it is limited only to the factors which were gathered under research ethics approval, for example, student GPA was not included due to limitations on internal ethics approval. Another important point to note is that modeling for responses to the professional skills survey assumed that the scale between the points was continuous and linear. It is important to recognize that while this may not be completely accurate and can add error to the model, ratings between 0 and 1 on all questions for both surveys indicated directional (increasing) and incremental development of skills, which was deemed to be sufficient to use linear modeling to investigate important factors. A similar approach was described in Knight & Novoselich, (2017) where linear modeling was used to investigate factors influencing self-reported leadership skills on a national student survey.

All results from the statistical analysis are reported at the 95% confidence level, or when $p<0.05$. Each of the three research questions were explored through the statistical tests reported in Table 3.

Table 3. Tabulation of statistical tests aligned with research questions.

Research Question	Statistical Test
Can project-based learning in a technical course significantly increase self-reported professional skills as measured by two surveys?	One tailed t-test for pre- and post- survey data
What are the factors in the context of technical project-based learning that influence professional skills development?	General linear model (GLM)
Is there a student demographic that performed significantly better or worse on assessment types in this particular class?	Two-tailed t-test, GLM, HLM

Limitations

The use of a case study has benefits and drawbacks. While it can be a useful tool to share practical experience, it is important to note that there are many factors which could limit repeatability in new contexts. Another important factor is that multiple interventions were conducted simultaneously in comparison to traditional course design, for example the course made use of blended delivery and technological mediated learning, active tutorials and project-based learning; it is therefore difficult to ascertain whether the effects observed are as a result of any one specific intervention. Another limitation to this study is that self-assessment methods have been shown to be biased in some cases. For example, Mabe & West (1982) have shown that there are several factors which can influence the validity of self-assessment, including user belief that anonymity will be violated. We have attempted to circumvent this perception via the ethics approval process to administer the surveys within our institution. Before the surveys were administered, a presentation clarifying how the survey results would be used was made for the students. Students were given a handout clarifying that survey results would be kept confidential, anonymous (except to pair pre- and post- surveys), and that the surveys would be placed in a sealed envelope and not be opened until after final grades were submitted for the course.

A further limitation in the study design is that this course was offered in a condensed format during the summer months. As a result, there may be some selection bias with respect to the students that were involved. Often students taking summer courses are either repeating the course or are attempting to get ahead in their sequence, which may have resulted in a sample that is unrepresentative of the population. Students who must repeat courses with lab sections are often given credit if they have previously passed the labs, however due to the nature of the course it was not possible to make this arrangement, which may have influenced student attitudes.

RESULTS

Description of the Sample

There were 48 (of 53) students who consented to be included in the study, ten females and 38 males. Each student was assigned randomly to a lab team for the semester (all five labs). There were 37 students in mechanical engineering and nine in civil engineering (two students did not report department). A subset of 38 students completed the Graduate Attributes survey, while a subset of 37 students completed the CDIO survey; some students who completed the Graduate Attribute survey did not complete the CDIO survey and vice versa. Data for all 48 students were used to analyse differences in assessment performance, while data from the 37 or 38 students were used for the analyses relating to factors associated with professional skills development as indicated by survey responses. Descriptive statistics are tabulated for each factor in Table 4.

Table 4. Descriptive statistics for each factor.

	Gender		Year of Study				Program*	
	Female	Male	1	2	3	4	Civil	Mechanical
Assessment Results	10	38	2	14	28	4	9	37
Graduate Attribute Survey	6	32	2	11	21	4	7	29
CDIO Survey	7	30	2	12	20	3	7	28

*Program information was not available for two students.

Professional Skills Development

The graduate attribute survey was previously tested with another group of students for reliability on the twelve CEAB graduate attributes in Brennan & Hugo (2016). The CDIO survey has been administered to measure professional skills development and is currently being analysed for reliability over ten years of data (thesis is in progress). In previous work (Cloutier et al., 2012) the syllabus has been correlated to CEAB graduate attributes 2-12. A Cronbach alpha analysis revealed that all mappings were “adequate” (Milliken, 2010) attaining an alpha of at least 0.7.

t-Test for Paired Means on Both Surveys

A paired sample t-test for all attributes was performed on responses to the CDIO and Graduate Attributes survey (this formed a total of 23 tests as the CDIO survey only included questions associated to graduate attributes 2-12). The alternate hypothesis for this test was that the difference in post and pre-responses was statistically significantly greater than zero (i.e. that there was a statistically significant increase in this skill); results are tabulated in Table 5. All results were found to meet the Shapiro-Wilks test for normality.

Table 5. Graduate attributes by survey, p-value for normality test, mean, standard deviation, sample size and paired sample t-test p-value. Highlighted values did not increase significantly.

Survey, Attribute	S-W normality	Paired Mean	Standard Deviation	N	p-value
CDIO GA2 - Problem Analysis	p>0.100	0.072	0.12	37	0.000
CDIO GA3 - Investigation	p>0.100	0.096	0.15	37	0.000
CDIO GA4 - Design	p>0.100	0.065	0.16	37	0.008
CDIO GA5 - Use of Engineering Tools	p>0.100	0.092	0.20	37	0.004
CDIO GA6 - Individual and Team work	p>0.100	0.044	0.15	37	0.037
CDIO GA7 - Communication skills	p>0.100	0.041	0.13	37	0.033
CDIO GA8 - Professionalism	p>0.100	0.016	0.15	37	0.260
CDIO GA9 - Impact of Engineering on Society and Environment	p>0.100	0.060	0.15	37	0.009
CDIO GA10 - Ethics and Equity	p>0.100	-0.015	0.15	35*	0.666
CDIO GA11 - Economics and Project Management	p>0.100	0.055	0.18	37	0.033
CDIO GA12 - Lifelong learning	p>0.100	0.032	0.14	37	0.094
GA1 - Knowledge base for engineering	p>0.100	0.16	0.18	38	0.000
GA2 - Problem Analysis	p>0.100	0.15	0.21	38	0.000
GA3 - Investigation	p>0.100	0.13	0.20	38	0.000
GA4 - Design	p>0.100	0.11	0.23	38	0.004
GA5 - Use of Engineering Tools	p>0.100	0.13	0.17	38	0.000
GA6 - Individual and Team work	p>0.100	0.060	0.16	38	0.015
GA7 - Communication skills	p=0.092	0.10	0.17	38	0.001
GA8 - Professionalism	p=0.070	0.00	0.20	38	0.500
GA9 - Impact of Engineering on Society and Environment	p>0.100	0.026	0.19	38	0.199
GA10 - Ethics and Equity	p>0.100	0.035	0.16	38	0.088
GA11 - Economics and Project Management	p>0.100	0.079	0.17	38	0.003
GA12 - Lifelong learning	p>0.100	0.11	0.16	38	0.000

* Two outliers were removed from this analysis after attaining a significant p-value in Grubb's test. One outlier was abnormally high, and one abnormally low. The finding of significance was not affected by this change

There were two attributes which did not increase significantly across both surveys. The first was *Attribute 8 – Professionalism*. Further examination of the questions associated with this attribute reveals that this finding is not completely surprising as most of the questions mention themes which were not dealt with explicitly in this course. The finding for *Attribute 10 – Ethics and Equity*, however, is a bit more surprising, as the CDIO survey actually indicated a decrease in this attribute. This was the only attribute of all 23 tests that indicated a decrease. Looking more closely, this decrease was accounted for from responses to CDIO questions 2.5.5 Equity and Diversity and 2.5.2 Professional Behaviour and Responsibility (highlighted in Table 6). Question 18 on the Graduate Attributes survey was found to have a negative response as well but did not contribute enough weight to cause negative growth in the attribute overall. The questions for this attribute are tabulated in Table 6 for convenience.

Table 6. Questions associated with Attribute 10 – Ethics and equity. Highlighted questions contributed the most to lack of growth in this attribute.

Survey	**Questions associated with Attribute 10 – Ethics and Equity**
GA Survey	Q18. Admit when you have made a mistake.
	Q37. Analyse opposing positions on an issue and make a judgment based on the evidence.
CDIO Survey	4.1.5 Contemporary issues and values
	2.5.5 Equity and Diversity
	2.5.2 Professional behaviour and responsibility

An investigation of a box plots indicates that the second-year students account for the majority of the negative response (though this difference was not statistically significant).

Students indicated they were less confident in their ability to admit when they made a mistake after the course, possibly due to conflicts that arose in the team activities. Conflict resolution was not explicitly dealt with in this course but could indicate an area of growth for future professional development in such classes.

Attribute 9 – Impact of engineering on society and the environment was found to increase significantly according to the CDIO survey, while the Graduate Attributes survey showed no significant increase. This is not surprising as the questions appear to capture slightly different themes related to this attribute. The questions for Attribute 9 are tabulated in Table 7 for convenience, with Q4 contributing most to the insignificant growth of this attribute.

Table 7. Questions associated with Attribute 9 – Impact of engineering on society and the environment for Graduate Attributes and CDIO Survey. Highlighted question contributed the most to lack of growth in this attribute.

Survey	**Questions associated with Attribute 9 – Impact of engineering on society and the environment**
GA Survey	Q4. Identify the interactions that an engineering project has with the economic, social, health, safety, legal, & cultural aspects of society.
	Q27. Apply technical, social, and environmental criteria to guide trade-offs between design alternatives.
	Q34. Incorporate sustainability considerations in project decision-making.
CDIO Survey	2.4.1 Initiative and willingness to make decisions in the face of uncertainty
	4.1.2 The impact of engineering on society and the environment
	4.1.7 Sustainability and the need for sustainable development
	4.1.4 The historical and cultural context
	4.4.6 Design for sustainability, safety, operability, aesthetics and other objectives
	4.5.1 Designing a sustainable implementation process
	4.6.1 Designing and optimizing sustainable and safe operations
	4.6.3 Supporting the system lifecycle

Further inspection of a boxplot for Attribute 9 demonstrated responses from fourth year students contributed the most negative result, with second and third years having the most gain in this area, though the differences are not statistically significant. This may be because fourth years enrolled in this course are more likely to be taking it as a repeat due to previous failed attempts.

Attribute 12 – Lifelong Learning was found to increase significantly on the Graduate Attributes survey, but not on the CDIO Survey. The questions are tabulated in Table 8 for convenience with question 2.4.6 *Lifelong learning and educating others* highlighted in the table as this is the question that had the least growth in this attribute. It is a possibility that students were confused by the term “lifelong learning” which can take on many meanings, or they were unable to link the current project-based learning activity to the development of lifelong learning skills. This could indicate a lost learning opportunity and should be considered for future discussion within the course.

Table 8. Questions associated with Attribute 12 – lifelong learning from both surveys. Highlighted question contributed the most to lack of growth in this attribute.

	Questions associated with Attribute 12 – Lifelong Learning
GA Survey	Q5. Recognize your strengths and weaknesses when working on a specific problem.
	Q23. Identify the best approach that is suited to your learning style.
	Q32. Use technical literature or other information sources to fill a gap in your knowledge.
CDIO Surveys	2.4.5 Self-awareness, meta-cognition, and knowledge integration
	2.4.6 Lifelong learning and educating others
	2.5.3 Proactively planning for one's career
	2.5.4 Staying current on the world of engineering
	2.5.7 Vision and intention in life
	4.1.6 Developing a global perspective

General Linear Model for Survey Responses on Both Surveys

A general linear model was then generated for responses to survey questions on the Graduate Attribute and CDIO survey. Factors which were examined were lab group, gender, department, and year in program. Lab group was examined to better understand whether a student being placed in a particular group impacted their perception of professional skills development – for example students on a "strong team" may have felt more positively about their professional skills development than those having a negative team experience. Gender was examined to verify whether there were any differences in the groups' perception of professional skills, and where those gaps were. Department was examined to verify whether mechanical and civil students perceived their experiences in a similar way, and year in program (1-4) was used to distinguish whether this impacted students' perceived development of professional skills.

Lab group, year in program, and gender were not found to be significant factors for graduate attribute development in the CDIO survey. Only two of the twelve attributes on the Graduate Attributes Survey were found to have significant factors: *Attribute 1 – Knowledge base for engineering* and *11 – Economics and project management.* In a Cronbach's alpha analysis both of these factors were found to be questionable to acceptable (alpha value 60-70), which contradicts findings from a previous study where these attributes were found to have acceptable alphas >0.7 (Brennan & Hugo, 2016). Given that all other factors were found to be insignificant across the other attributes, these factors warranted further discussion, with the significant attributes and associated factors tabulated in Table 9:

Table 9. Tabulation of R-square and p-value for factors: lab group, gender, department, year in program, lack of fit, on general linear model. Highlighted values were significant.

	Lab Group p-value	Gender p-value	Department p-value	Year in Program p-value	Lack of Fit p-value	R-squared value
GA1 - Knowledge base for engineering	0.400	0.524	0.041	0.062	0.062	58.93%
GA11 - Economics and Project Management	0.555	0.013	0.295	0.014	0.475	61.79%

Department was found to be a statistically significant factor for *Attribute 1 - a knowledge base for engineering*. Closer inspection of the model indicated that civil engineering students rated themselves significantly lower in growth of this attribute. This may reflect a difference in students' comfort level with the technical material covered in this course, which may put a higher emphasis on dynamics than civil students are accustomed to. For responses to Graduate Attribute survey questions on *Attribute 11 –Economics and Project Management*, students' year in program and gender were both factors in their responses. Women rated themselves significantly higher than their male counterparts, with fourth and first years ranking themselves significantly lower than third years (there was no significant difference between second years and the others) in a fisher test for mean differences.

General Linear Model Relating High and Low Rank on Project-Based Learning Lab Assessment and Professional Skills Development

Students were grouped by their overall rank on assessment of the project-based learning labs into two groups (high and low). A general linear model was performed for responses to surveys on professional skills development. It was found that there was no significant difference between the groups in self-evaluated performance on any skills measured by the Graduate Attributes survey, however on the CDIO survey groups performed significantly differently on six of the eleven measured attributes, tabulated in Table 10.

Table 10. Attributes with significant performance differences between high and low-ranking students on PjBL lab assessments.

Survey - Attribute	Coefficient of Higher Ranked Group	p-value	R-squared value
CDIO4 - Design	0.15	0.003	22.64%
CDIO6 - Individual and Team work	0.13	0.004	20.92%
CDIO7 - Communication skills	0.12	0.007	19.01%
CDIO8 - Professionalism	0.10	0.043	11.18%
CDIO9 - Impact of Engineering on Society and Environment	0.11	0.019	14.78%
CDIO12 – Lifelong learning	0.094	0.047	10.81%

This finding confirms that students who ranked well on labs reported significantly higher increases on these attributes, however the claim cannot be reversed (because students developed more in these attributes it cannot be claimed that this is the reason they performed significantly better on laboratories). It is logical, however, that there is some relationship between these two. Further inspection of the R-squared value for each of the attributes indicates that the effect size can be classified as medium to large. Cohen, (1988) previously reported that an r-squared value of between 9%-25% be classified as medium, and anything larger than 25% be classified as large, while a more recent empirical study by Hemphill, (2003) has suggested that values greater than 9% can be classified as large.

For all reported significant factors, the higher performing group coefficient was reported. In the models, the lower performing coefficient was zero, therefore each factor's coefficient gives a direct indication of how much higher the skills were reported over the lower performing group.

General Linear Model Relating High and Low Rank on Peer Assessment and Significant Professional Skills Development

Peer assessments were performed at the end of each of the five PjBL activities for each of the students in their assigned group. To get an indication of whether students being grouped into the same teams throughout the semester biased their results on peer assessments, a hierarchical linear model was performed nesting student grades on peer assessments within their teams (ie. Did teams mark themselves significantly differently than others). In this model teams were not found to be a significant factor (p=0.624). This meant that there was no confounding of student peer assessment grades based on the team they were in, and this factor was removed from further analysis.

Students were then grouped according to how they ranked with respect to their peers on peer assessments. Top students were placed in group 1 and all below average ranked students were placed in group 2. Their survey results were compared for significant differences between these two groups. P-value and r-squared values for the significant attributes are tabulated in Table 11.

Table 11. Attributes with significantly different performance between high and low-ranking students on peer assessments.

Survey-Attribute	Coefficient of Higher Ranked Group	p-value	R-squared value
CDIO4 - Design	0.10	0.056*	10.07%
CDIO5 - Use of Engineering Tools	0.15	0.028	13.02%
CDIO6 - Individual and Team work	0.12	0.019	14.80%
CDIO7 - Communication skills	0.088	0.049*	10.59%
CDIO9 - Impact of Engineering on Society and Environment	0.12	0.015	15.86%
CDIO11 - Economics and Project Management	0.14	0.018	15.05%

*Reported although at the cusp of significance.

A similar statement to the relationship previously made between ranking on lab assessment and attribute development can be made here – students who performed significantly better on the peer assessments tended to develop better in the above areas. Again, it cannot be claimed that because students developed these attributes they performed better on their peer assessments. Qualitatively it stands to reason that there is some relationship between them.

For all reported significant factors, the higher performing group coefficient was reported. In the models, the lower performing coefficient was zero, therefore each factor's coefficient gives a direct indication of how much higher the skills were reported over the lower performing group.

This finding also helps to support the validity of self-assessment responses to the CDIO survey. The above table demonstrates for these particular attributes that students who were ranked higher by their peers on peer assessment during the course (participation, leadership, listening, feedback cooperation and time management) rated themselves significantly higher on related attributes 6, 7, and 11. It is an interesting result that the graduate attributes survey did not show any significant differences between the two groups. This may reveal differences in the ability of the surveys to measure these skills accurately.

Rank of Overall Professional Skills Growth

Placing the attributes in rank order reveals that the top five growth areas were mainly in the more technically-oriented skills (Attributes 1-5). Attribute 2, 3, and 5 were the only three professional skills making the top five ranking across both surveys, tabulated in Table 12.

Table 12. Ranking of top five skills by growth and significance by survey.

Graduate Attributes Survey	CDIO Survey
1 – Knowledge base for engineering	2 – Problem Analysis
2 – Problem Analysis	3 – Investigation
3 – Investigation	5 – Use of Engineering Tools
5 – Use of Engineering Tools	9 – Impact of Engineering on Society and Environment
12 – Lifelong learning	11 – Economics and Project Management

These findings indicate that project-based learning can be a useful tool for professional skills development in a technical course without sacrificing the development of technically-oriented engineering acumen (referred to as dual-impact learning experiences in CDIO).

Assessment Performance Comparison

t-test Comparing Individual vs. Group Quiz Grades

A paired t-test was performed for quiz grades between student individual attempt and their combined grade for the same exam (a weighted average of: 90% individual quiz grade and 10% team's grade). There was a significant increase between the two grades for all exams ($p=0.000$ for all five exams), $n=48$. This does not necessarily indicate that the lower-ranked students learned more due to this practice. What it does appear to indicate is that there was no harm for the higher-ranked students (their grades were not reduced). An increase in student grades may not be the only externality of such a practice. Students must practice communicating as they articulate their approach and convince their team why their solution made sense. Students also gained experience in offering and receiving feedback: students articulated how their approaches could be improved. Time-management was also practiced, as students implemented techniques to complete the one-hour quiz as a team in 30-minutes or less. The statistically significant increase in communication and teamwork attributes observed in the previous section may be partially explained by this experience.

Factors Influencing Performance on Assessment Types

To discover whether there was a student demographic who performed significantly differently on assessment type in this course, general linear models were created relating lab group, gender, department of study, and year in program to grades on various assessment types. The only factor found to be significant at the 95% confidence level was gender and performance on exams, with women performing significantly worse than their male counterparts. Findings from the model are tabulated in Table 13.

Table 13. Summary of results from general linear model relating gender to performance on assessment types.

Assessment Type	Coefficient for Female	P-value	R-squared value
PjBL Labs	-0.017	0.262	2.73%
Exams	-0.15	0.000	27.15%
Cornell Notes	0.21	0.069	7.02%
Peer Review	-0.0023	0.909	0.03%

Coefficient for the female term in the model was reported (with males taken as the reference level), which gives an indication of the magnitude of contribution by the female term to the model (normalized).

These findings indicate that there was no demographic of student favoured or challenged by this type of course delivery, with the exception of the statistically significant lower performance by females on quizzes and exams. It is unclear why females performed significantly lower on these assessment types. Taken with the finding from the professional skills survey that females performed significantly better in the area of economics and project management (the only attribute in which there was a statistically significant difference between the genders), it is possible that the female students concentrated more of their time supporting their groups on the projects while sacrificing time to study for their exams. This finding may also indicate a bias by teaching assistants in marking, however it is not possible to verify this claim for this course. Yet another explanation may come from the finding that females performed better than males on the Cornell Notes (though not statistically significantly better). This may indicate that the female students spent more time perfecting their Cornell Notes, which did not translate into performance on exams. This finding may indicate that students who sacrificed performance on Cornell Notes by jumping to practicing technical problems performed better in general, however there is no statistically significant evidence to substantiate this finding.

A general linear model was created relating lab group, gender, program of study and year in program to performance on PjBL assessments. Lab group and year in program where both found to be statistically significant ($p<0.05$). Lack of fit was significant ($p<0.05$), however R-squared was also quite high at 84.41%. A hierarchical model was therefore created nesting year in program within lab groups, and was found to be significant ($p=0.001$). This finding indicates that there was a significant difference on performance between students in different program years when their lab groups were accounted for. This model had no lack of fit and had an R-squared value of 95.61% indicating that these two factors explained almost all variance in this model. Further inspection of a boxplot of lab grades and a fisher difference of means test revealed that fourth year students performed significantly lower than the other students in the labs. As there were only four fourth years in this course it is likely that their performance is an inaccurate representation of what fourth year performance may look like in general for this class. It should be noted, however, that this course is traditionally offered in the second year of the program, so it is possible that students in fourth year are taking this course for the second or third time and are either not motivated to the level the other students are or perform lower in experiential learning for some other reason. The finding that lab group was a factor in lab performance is also an important one as it may indicate that group dynamics played a role in student success in the labs.

Reflections

While the findings in this paper present a departing point for future discussion on blended and project-based learning, it is important to recognize that we cannot make a claim about which intervention led to the development of professional skills in the offering of this course. While it is clear from the findings that the mix of active PjBL learning and technology-mediated blended delivery, increased many professional skills, the findings here do not say anything about whether the same depth of development could have been achieved with less or different intervention. A recommendation for future studies would be to conduct smaller-scale experiences where the effect of one variable could be more easily isolated and the response to that variable measured.

CONCLUSION

In general it can be concluded that the vast majority of students performed as well as their peers in the demanding and complex environment of open-ended project-based learning. Females performed significantly worse than males on quizzes and exams only. This finding is inconsistent with the theory and requires further investigation. Fourth year students performed significantly worse than students from all other years on assessments in the project-based learning laboratories. This may be because of a lack of motivation on the part of the fourth-year students in taking this second or third year course later on in their program or because of having to repeat the class due to failure in previous terms. Students repeating the course were not given credit for previous attempts in the course due to the addition of project-based labs in this offering, which may have negatively biased them.

All except six of the 23 attributes measured were found to increase significantly in a paired t-test for the two surveys indicating that there was a significant improvement in graduate attributes development. *Attribute 8 – Professionalism* and *Attribute 10 – Ethics and Equity* did not improve significantly on either survey, which is not surprising as these themes were not dealt with explicitly in the course. *Attribute 9 – Impact of engineering on society and the environment* increased significantly only on the CDIO survey, with no increase found on the graduate attributes survey, and *Attribute 12 – Lifelong learning* only increasing significantly on the Graduate Attributes survey. These contradictions were likely due to the nuanced thematic differences between the questions on the two surveys. An analysis of the findings from the survey responses indicates that technical skills and professional skills can both be developed in tandem in a project-based learning course; however, there are limits to which all of the attributes can be developed simultaneously, as expected.

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BIOGRAPHICAL INFORMATION

Alexandra Meikleham is an MSc student in Mechanical engineering at the University of Calgary in Calgary, Canada. Her current research focuses on human-centered design and on engineering curriculum development.

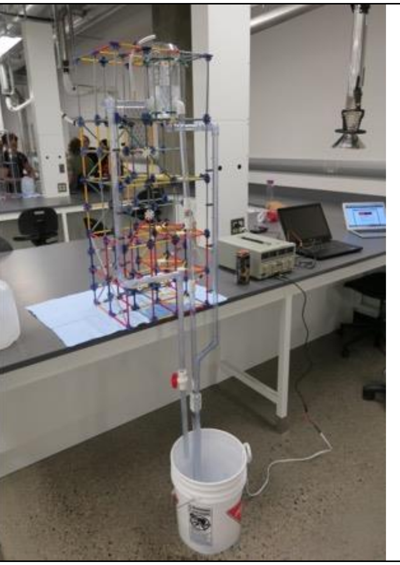
Ron Hugo is Professor of Mechanical and Manufacturing Engineering and the Chair in Engineering Education Innovation in the Schulich School of Engineering. His research interests are in the areas of experimental fluid dynamics, energy systems, and engineering education.

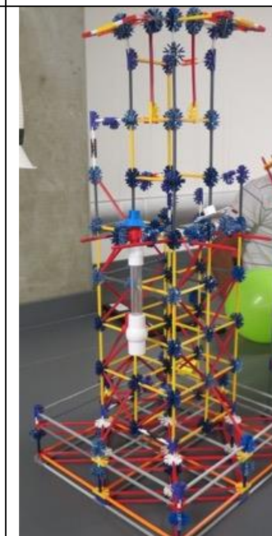
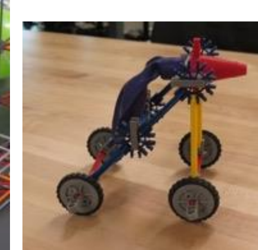
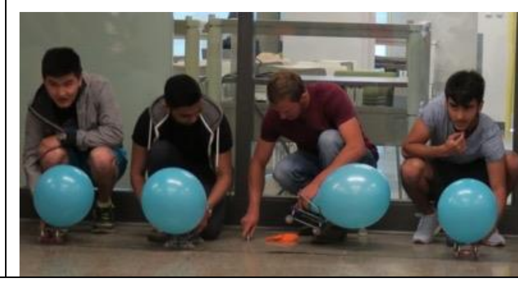
Robert Brennan is a Professor of Mechanical and Manufacturing Engineering and Head of Department (Mechanical & Manufacturing Engineering) at the Schulich School of Engineering. He has served on the Canadian Design Engineering Network (CDEN) steering committee, chaired the organizing committee for the second CDEN conference, chaired the Schulich School of Engineering's first Engineering Education Summit, served as an organizing committee member for the CIRP International Design Seminar, and is the current American Society for Engineering Education (ASEE) campus representative for the University of Calgary.

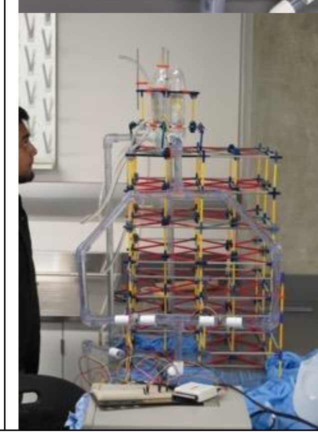
Corresponding author

Alexandra Meikleham
University of Calgary
2500 University Dr. NW
Calgary, Alberta T2N1N4
1-514-567-8488
alexandra.meikleh1@ucalgary.ca

APPENDIX

Lab	Topic	Description	Objectives	Picture
1	Constant head tank and calibration of a flow meter	Students designed and built a constant head tank apparatus using a 12V DC power supply, submersible pump, ½" clear pvc piping and connectors, Knex structure, and data acquisition device.	To use a constant head tank to plan and perform the calibration of a turbine flow meter using a USB-6009 data acquisition device; Understand averaging techniques to achieve statistically-converged flow meter data; To quantify the volumetric flow rate of an electrically driven submersible pump as a function of input voltage when operating under steady state conditions; Clearly communicate the process and findings of the experiment in a technical memo.	
2	U-tube manometer	Students used their K'nex structures to assemble a U-tube water manometer using tygon tubing, barbed couplers and valves to measure the pressure in a balloon.	To design and assemble a support structure that is stable and able to support a vertical U-tube manometer of Tygon tubing; To specify the design length of Tygon tubing and required dimensions of the structure to support a U-tube manometer, given expected pressure inside a vessel (balloon); Demonstrate the relationship between volume of air and pressure of a balloon; Utilize averaging and sampling techniques to achieve consistent results; Clearly communicate the design and	

			experimental procedure and findings in a technical poster.	
3	Momentum Transfer	Quantify momentum transfer on a curved and a flat plate of air flow through a 3D printed nozzle. Utilize the best performing nozzle to compete in an balloon car race.	Design and prototype (3D print) two nozzles, test and compare performance in terms of produced thrust; Research, understand and articulate the factors of nozzle design that affect performance, discuss tradeoffs that exist in the design process; Utilize control volume analysis to verify experiments against theory; Build a calibration unit and quantify thrust from a balloon/nozzle assembly using experimental data; Design and build a car for a balloon / nozzle combination for maximum performance; Demonstrate performance of top nozzle in a K'NEX car race (covering a fixed distance of 20' in the shortest amount of time).	  

4	Dimensional Analysis and Pump Performance	Students built a small holding tank with a plastic container, submersible pump and 2m of tygon tubing. Hall effects sensor data was used to verify RPMs.	To investigate non-dimensional parameters for a submersible pump; Utilize hall effects sensor to measure RPM of a brushless motor; Conduct experiments to determine the pump performance curve, system curve and efficiency of a pump and determine the operating point for the system.	
5	Head loss in Pipes	Students utilized their constant head tanks from experiment 1 to quantify the head loss as measured from a series of pressure taps and velocity using flow meters across a variety of pipe networks.	To determine the roughness factor of a length of ½” clear PVC pipe To determine the energy loss due to a variety of standard pipe components as a function of Reynolds number: Flow meter, Ball valve (at a variety of openings angles), Two parallel, symmetric circuits of a variety of pipe components, Two parallel, asymmetric circuits of a variety of pipe components.	 

CDIO survey

Name: ___________________ Age: _________ Date: ___________________

Please indicate which of the five levels of proficiency that you feel you are at:

Scale:

1 To have experienced or been exposed to
2 To be able to participate in and contribute to
3 To be able to understand and explain
4 To be skilled in the practice or implementation of
5 To be able to lead or innovate in

Proficiency Level (1-5)

2 PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES

2.1 ANALYTICAL REASONING AND PROBLEM SOLVING
2.1.1 Problem Identification and Formulation . . . . . ____
2.1.2 Modeling . . . . . ____
2.1.3 Estimation and Qualitative Analysis . . . . . ____
2.1.4 Analysis With Uncertainty . . . . . ____
2.1.5 Solution and Recommendation . . . . . ____

2.2 EXPERIMENTATION, INVESTIGATION AND KNOWLEDGE DISCOVERY
2.2.1 Hypothesis Formulation . . . . . . ____
2.2.2 Survey of Print and Electronic Literature . . . . ____
2.2.3 Experimental Inquiry . . . . . . ____
2.2.4 Hypothesis, Test, and Defense . . . . . . ____

2.3 SYSTEM THINKING
2.3.1 Thinking Holistically . . . . ____
2.3.2 Emergence and Interactions in Systems . . . . . ____
2.3.3 Prioritization and Focus . . . . . ____
2.3.4 Trade-offs, Judgment and Balance in Resolution . . . . ____

2.4 ATTITUDES, THOUGHT AND LEARNING
2.4.1 Initiative and the Willingness to Make Decisions in the Face of Uncertainty . ____
2.4.2 Perseverance, resourcefulness, flexibility, responsibility, and will and urgency to deliver ____
2.4.3 Creative Thinking . . . . ____
2.4.4 Critical Thinking . . . . ____
2.4.5 Self-awareness, Meta-cognition and Knowledge Integration . . . ____
2.4.6 Lifelong Learning and Educating Others . . . . . ____
2.4.7 Time and Resource Management . . . . . ____

2.5 ETHICS, RESPONSIBILITY, EQUITY, AND CORE PERSONAL VALUES
2.5.1 Ethics, Integrity and Social Responsibility . . . . . ____
2.5.2 Professional Behavior and Responsibility . . . . . ____
2.5.3 Proactively Planning for One's Career . . . . . ____
2.5.4 Staying Current on the World of Engineering . . . . ____
2.5.5 Equity and Diversity . . . . ____
2.5.6 Trust and Loyalty . . . . ____
2.5.7 Vision and Intention in Life . . . . . . ____

3 INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION

3.1 TEAMWORK
3.1.1 Forming Effective Teams . . . . ____
3.1.2 Team Operation . . . . ____
3.1.3 Team Growth and Evolution . . . . . . ____
3.1.4 Team Leadership . . . . ____
3.1.5 Technical and Multi-disciplinary Teaming . . . . . ____

3.2 COMMUNICATIONS
3.2.1 Communications Strategy . . . . . . ____
3.2.2 Communications Structure . . . . . . ____
3.2.3 Written Communication . . . . ____
3.2.4 Electronic/Multimedia Communication . . . . . ____
3.2.5 Graphical Communication . . . . . . ____

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Name: ________________ Age: ________ Date: ________________

3.2.6 Oral Presentation . . . . ____
3.2.7 Inquiry, Listening and Dialog . . . . . . ____
3.2.8 Negotiation, Compromise and Conflict Resolution . . . ____
3.2.9 Advocacy . . . . ____
3.2.10 Establishing Diverse Connections, networking . . . ____

3.3 COMMUNICATIONS IN A FOREIGN LANGUAGE
3.3.1 Communications in English . . . . . . ____
3.3.2 Communications in languages of regional industrial nations . . . ____
3.3.3 Communications in other languages . . . . . ____

4 CONCEIVING, DESIGNING, IMPLEMENTING, AND OPERATING SYSTEMS IN THE ENTERPRISE, SOCIETAL AND ENVIRONMENTAL CONTEXT – INNOVATION

4.1 EXTERNAL, SOCIETAL, ECONOMIC AND ENVIRONMENTAL CONTEXT
4.1.1 Roles and Responsibility of Engineers . . . . . ____
4.1.2 The Impact of Engineering on Society and the Environment . . . ____
4.1.3 Society's Regulation of Engineering . . . . . ____
4.1.4 The Historical and Cultural Context . . . . . ____
4.1.5 Contemporary Issues and Values . . . . . . ____
4.1.6 Developing a Global Perspective . . . . . . ____
4.1.7 Sustainability and the need for sustainable development . . . ____

4.2 ENTERPRISE AND BUSINESS CONTEXT
4.2.1 Appreciating Different Enterprise Cultures . . . . ____
4.2.2 Enterprise Stakeholders, Strategy and Goals . . . . ____
4.2.3 Technical Entrepreneurship . . . . . . ____
4.2.4 Working in Organizations . . . . . . ____
4.2.5 Engineering Project Finance and Economics . . . . ____
4.2.6 New Technology Development, Assessment and Infusion . . . ____
4.2.7 Working in international organizations . . . . . ____

4.3 CONCEIVING, SYSTEMS ENGINEERING AND MANAGEMENT
4.3.1 Understanding Needs and Setting Goals . . . . . ____
4.3.2 Defining Function, Concept and Architecture . . . . ____
4.3.3 Modeling of System and Insuring Goals Can Be Met . . . . ____
4.3.4 System Engineering and Development Project Management . . . ____

4.4 DESIGNING
4.4.1 The Design Process . . . . ____
4.4.2 The Design Process Phasing and Approaches . . . . ____
4.4.3 Utilization of Knowledge in Design . . . . . . ____
4.4.4 Disciplinary Design . . . . ____
4.4.5 Multidisciplinary Design . . . . ____
4.4.6 Design for Sustainability, Safety, Operability, Aesthetics and other Objectives . ____

4.5 IMPLEMENTING
4.5.1 Designing a Sustainable Implementation Process . . . . ____
4.5.2 Hardware Manufacturing Process . . . . . ____
4.5.3 Software Implementing Process . . . . . . ____
4.5.4 Hardware Software Integration . . . . . . ____
4.5.5 Test, Verification, Validation, and Certification . . . . ____
4.5.6 Implementation Management . . . . . . ____

4.6 OPERATING
4.6.1 Designing and Optimizing Sustainable and Safe Operations . . . ____
4.6.2 Training and Operations . . . . . . ____
4.6.3 Supporting the System Lifecycle . . . . . . ____
4.6.4 System Improvement and Evolution . . . . . ____
4.6.5 Disposal and Life-End Issues . . . . . . ____
4.6.6 Operations Management . . . . . . ____

4.7 LEADING ENGINEERING ENDEAVORS
4.7.1 Thinking Creatively and Imagining Possibilities . . . . ____
4.7.2 Defining the Solution . . . . ____
4.7.3 Creating New Solution Concepts . . . . . . ____
4.7.4 Building and Leading and Organization and .Extended Organization . . ____

Name: __________________ Age: _________ Date: __________________

4.7.5 Planning and Managing a Project to Completion . . . . . _____
4.7.6 Exercising Project/Solution Judgment . . . . . . _____
4.7.7 Innovation – the conception, design and introduction of new goods and services _____
4.7.8 Invention – the development of new devices, materials or processes that enable new goods and services . . . . _____
4.7.9 Implementation and Operation – the creation and operation of the goods and services that will deliver value . . . . _____

4.8 ENGINEERING ENTREPRENEURSHIP

4.8.1 Company Founding, Formulation and Organization . . . . . _____
4.8.2 Business Plan Development . . . . . . _____
4.8.3 Company Capitalization and Finances . . . . . . _____
4.8.4 Innovative Product Marketing . . . . _____
4.8.5 Conceiving products and services around new technologies . . . _____
4.8.6 The Innovation System, Networks, Infrastructure and Services . . _____
4.8.7 Building the Team and Initiating Engineering Processes (conceiving, designing, implementing and operating) . . . . _____
4.8.8 Managing Intellectual Property . . . . _____

Peer Assessment Rubric

Peer Assessment Collaboration Rubric – Exp #1 / Constant Head Tank

(Weight: 2% of final grade) Team #: ______ Date: ____________________

	4	3	2	1
Participation	Group member participated fully and was always on task in the lab activity.	Group member participated most of the time and was on task most of the time.	Group member participated but wasted time regularly or was rarely on task.	Group member did not participate, wasted time, or worked on unrelated material.
Leadership	Group member assumed leadership in an appropriate way when necessary by helping the group stay on track, encouraging group participation, posing solutions to problems, and having a positive attitude.	Group member sometimes assumed leadership in an appropriate way.	Group member usually allowed others to assume leadership or often dominated the group.	Group member did not assume leadership or assumed it in a nonproductive manner.
Listening	Group member listened carefully to others' ideas.	Group member usually listened to others' ideas.	Group member sometimes did not listen to others' ideas.	Group member did not listen to others and often interrupted them.
Feedback	Group member offered detailed, constructive feedback when appropriate.	Group member offered constructive feedback when appropriate.	Group member occasionally offered constructive feedback, but sometimes the comments were inappropriate or not useful.	Group member did not offer constructive or useful feedback.
Cooperation	Group member treated others respectfully and shared the workload fairly.	Group member usually treated others respectfully and shared the workload fairly.	Group member sometimes treated others disrespectfully or did not share the workload fairly.	Group member often treated others disrespectfully or did not share the workload fairly.
Time Management	Group member completed assigned tasks on time.	Group member usually completed assigned tasks on time and did not hold up progress on the projects because of incomplete work.	Group member often did not complete assigned tasks on time, and held up completion of project work.	Group member did not complete most of the assigned tasks on time and often forced the group to make last-minute adjustments and changes to accommodate missing work.

ENME 341: Experiment #1 – Constant Head Tank
Source: Intel Corporation - Intel Teach Program – Designing Effective Projects

Peer Assessment Collaboration Rubric – Exp #1 / Constant Head Tank

(Weight: 2% of final grade) Team #: ______ Date: ____________________

Write the proficiency level (1 to 4) from the rubric that fits each group members' participation in the box under the collaboration skill. Include your own name at the end of the list.

Group Member	Participation	Leadership	Listening	Feedback	Cooperation	Time Management
Your name (self eval.):						

Note: Be honest in your assessment. If a score of 4 is entered for every team member, all scores will be set to zero. This helps to prevent collusion within the group.

ENME 341: Experiment #1 – Constant Head Tank
Source: Intel Corporation - Intel Teach Program – Designing Effective Projects

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GENDER DIFFERENCES IN ENGINEERING STUDETNS' CHOICE OF STUDIES

Ásrún Matthíasdóttir

School of Science and Engineering, Reykjavik University

ABSTRACT

The Science, Technology, Engineering and Mathematics (STEM) sector is gender biased throughout, in schools, workplaces and academia. The development for gender equality is slow and stereotypes are still male dominated in STEM. The situation is complicated with many influencing factors that have been studied and dealt with for the last decades. To decide what education or training to achieve is among the most important decision in young peoples´ lives. The trend is that more males go for STEM studies while females go for subjects like education, health sciences and social sciences. It is important for engineering as a profession not only to attract both genders, but also to get a better understanding of the influencing factors when young persons are deciding what subject to select for their life. This paper presents an overview of the findings from a study focusing on gender differences in engineering students' choice of studies and discusses some ideas of what educators can do to change the situation. This topic touches on CDIO Standard 1 (program philosophy), 7 and 8 (new methods of teaching and learning).

KEYWORDS

STEM, Gender differences, Choice of studies, CDIO Standards: 1, 7, 8

INTRODUCTION

The fact that females are underrepresented in Science, Technology, Engineering and Mathematics (STEM) is problematic for society as well as for girls and women, giving them fewer opportunities for career and professional development and good salaries. For a society in need of more STEM skilled labour, to miss out almost half of the young population is a drawback. It is important to develop our understanding of of this gender inequality and get a better overview of what options there are to reduce the lack of interest in STEM studies and career choices among females.

The purpose of this study was to obtain more information on gender differences among engineering students' choice of studies, the most influencing factor and explore if there was a gender difference their computer use in education and computer skills before they entered the engineering studies. It is of interest to know the attitudes and gender differences among those who have already decided to study engineering and applied engineering. This information could guide us in the effort to recruit not only more females in engineering and applied engineering, but also more students into STEM subjects in general.

LITTERATURE REVIEW

To decide what study line to choose at university can be difficult for young persons. Many factors affect their decisions, e.g. social environmental influences, individuals' goals and interest, stereotypes, role models and media. STEM subjects have been male dominated over the years, while females go into subjects like health sciences (nursing and psychology), social sciences, and education. The situation has slowly improved and females are now better represented in some STEM fields, e.g. the medical and biology fields, but not in others, e.g. computer science and engineering. Many studies have been conducted in the field of gender bias in education, especially in STEM, to come forward with solutions. Thus, females' underrepresentation in STEM is well documented, many advices, models and guidelines have been designed, and projects carried out in order to improve the situation. Despite that, females are still underrepresented in STEM (Ashcraft, Eger, & Friend, 2012; Stoeger, Duan, Schirner, Greindl, & Ziegler, 2013; Liben & Coyle, 2014; Cheryan, Master, & Meltzoff, 2015; Matthiasdottir & Palsdottir, 2016; Funke, Berges, & Hubwieser, 2016).

There are many influencing factors when it comes to academic and career choices as personal perception and beliefs, with roots in people's personal experiences that are influenced by others, and the social environment. Achievement disparities between females and males are sometimes used to explain why women are underrepresented in STEM, but as females' achievements have improved, this is no longer a satisfactory explanation of gender inequalities in STEM participation. Interest was earlier considered a critical factor for educational choices (Benbow & Minor, 1986; Lapan, Shaughnessy, & Boggs, 1996; Su, Rounds, & Armstrong, 2009; van Tuijl & van der Molen, 2016), but a number of factors seem to shape peoples' interest, such as family, friends, school, and media and in fact societies' cultures as well (Eccles et al., 1993). Motivation, which is another factor that is considered to shape interest, has been shown to be strongly related to academic and career aspirations (Robnett & Leaper, 2013). Ability beliefs and giftedness have also been used to explain gender-related participation in STEM. Despite all this, researchers' focus is now no longer solely on personality traits (Stoeger et al., 2013) as gender different participation in STEM is a complex problem with many angles and with roots even in early childhood (van Tuijl & van der Molen, 2016).

There are studies into the influence of parents' expectations and social values, which are believed to explain to some extent why women do not enter STEM studies or leave the field for other more interesting jobs or studies (Preston, 1994). Educational opportunities and occupational choices have been discussed (Hänze & Berger, 2007) and technology self-efficacy and digital skills, which can influence educational choices. Studies have shown that students' STEM self-efficacy beliefs are important when they decide to take on further studies in STEM (Jansen, Scherer, & Schroeders, 2015; Brown, Concannon, Marx, Donaldson, & Black, 2016) and males report higher technology self-efficacy than females (Rohatgi, Scherer, & Hatlevik, 2016). The self-efficacy theory comes from Bandura and emphasises the influence of mastery of experience and vicarious learning experiences (Brown et al., 2016). In addition, access and use of computers in education influences and supports better academic performances, although some studies have demonstrates that this is not the situation in all areas (Paino & Renzulli, 2013).

More influencing factors shape students opinions and interests. The teacher's role is important and their teaching practice affects students' academic self-concepts, but the perceived quality of teaching in mathematics is not in favour of females (Lazarides & Ittel, 2012). Instruction methods are important because they influence students' self-concept. Cooperative instructions are more beneficial than direct instruction for students with low academic self-concept, because it makes them feel more competent (Hänze & Berger, 2007). This shows the importance of positive learning experience to build good STEM self-efficacy among not only females, but also males, to make them more interested in their studies.

In a report from the National Centre for Women in Science and Technology (NCWIT, http://www.ncwit.org), four areas are suggested as important in order to change gender imbalance in computer science: influence of education, students' environment, equalization, the media and the culture (Ashcraft et al., 2012). These areas can easily be applied to STEM.

The first area suggested in the NCWIT report is the role and influence of education, with reference to the influence of teaching and learning, which in STEM subjects is rarely specifically connected to the interests of females. The learning environment in STEM subjects is therefore not particularly encouraging for females. Research has shown the importance of linking study materials to the interests and experiences of students, as well as using active teaching methods that encourage collaboration. Research also suggests, that within technical fields, these methods are not used to the same extent as in many other fields (Ashcraft et al., 2012). It is important to explore teaching methods and see whether they can be changed to attract more students, not just women, but also men who could gain from different teaching methods. In this context, it is worrying that teachers often lack appropriate education in STEM (Ashcraft et al., 2012). Introduction to STEM and what opportunities are available for students after graduation can always be improved, using new media that young people are familiar with, both in primary and secondary schools.

Secondly, the effects of students' environment, the family, the community and the role models are emphasised in the NCWIT report. Females and males often encounter different behaviours and motivation that leads to different experiences early in life. The most important factors in decision-making about learning and career involve females' environment, parents, friends, teachers and the media. When STEM is not part of a positive impression the influence will affect the decision and guide them away from considering careers in STEM (Ashcraft et al., 2012).

It can be argued that women's attitudes within in the profession are important and numerous studies have shown that good models have a positive effect. One way is to get women, who have reached far in this area, to visit schools to show where education in STEM has led them. It is important to get more females to choose STEM in order to have good female models in the field and introduce these role models to younger women earlier in school. (Ashcraft et al., 2012).

Masculinity and gender roles are still strong predictors when it comes to technology self-efficacy (Huffman, Whetten, & Huffman, 2013). Women who are studying STEM subjects have overcome many barriers in their environment and may be less receptive to influence from a stereotypic environment, although Ertl, Luttenberger and Paechter (2017) concluded from their research that even this group is sensitive for stereotypic influence. Schuster and Martiny's (2017) research showed that women anticipate negative feelings in more stereotypical contexts than young men. Creating less stereotypic STEM environment could thus nurture more positive affect among females.

Thirdly, the NCWIT report refers to the influence of equalization, because it can be difficult to be the only female in the group and experiencing the masculine culture one does not belong too (Ashcraft et al., 2012). Cheryan et al. (2017) emphasize how masculine cultures in the STEM field can build up feelings of not belonging for women, but an early experience of STEM could change the masculine culture, stereotypes and role models. STEM fields have very different cultures (Cheryan et al., 2017) which raises the question of culture in technology, engineering, and mathematics, where women are underrepresented. Students have different educational experiences early on in school, and subjects like math and biology have been a part of the curriculum, but subjects like programming and even physics come later on or even not at all. Research has shown that gender differences in mathematics and other STEM subjects decreases in high school (Sadler, Sonnert, Hazari, & Tai, 2012), which gives opportunity to revise teaching methods and material. This does also support the opinion that introducing all STEM subjects earlier in kids' education influences positive attitudes and that programming should in fact be a compulsory subject at the lower school levels. This could establish a stronger feeling of belonging not only in computer science programs, but also in other STEM subjects where programming is now a part of the curriculum.

Fourthly, the effects of media and culture (Ashcraft et al., 2012). People in computer science, engineering, and physics are frequently shown as more socially awkward males in the media than in other STEM subjects as biology and chemistry. Typical examples are the characters in TV series like "The Big Bang Theory". We all laugh at them. These stereotypes serve as gatekeepers that can push women away from certain subjects and may limit their learning opportunities and career chances. Advertisements can also promote stereotypes, not only the pictures but also the wording that is often masculine, as it splits the world up in a way that is more accepted for men than for women. For some, these nerdy models are appealing, but for others they are not at all appealing. Video games are believed to have had a major impact on the negative trend for STEM, as they were at fist mainly addressed to boys, although now there are more games for girls and hopefully with positive influences.

Some young people, especially men, can like the nerdy male types, but as STEM is also for women we need to make sure that stereotype of engineering is appealing for both male and female. To broaden the STEM image we can use curriculum, role models, STEM environments and the media (Cheryan, Master, & Meltzoff, 2015; Cheryan, Zieger, Montoya, & Jiang, 2017). Both men and women must have a sense of belonging in STEM, but they do not all respond the same way to the stereotypes. Today's stereotypes can attract and scare off both genders, but we need to diversify current stereotypes so that all students believe they fit to the image to be successful in STEM (Cheryan et al., 2017).

The main aim of this study was to see if there were gender differences in students' motives for choosing to study engineering in a sample of engineering and applied engineering students. Secondary aim was to investigate if there were 1) gender differences in computer use in education prior to university, and 2) self-reported computer skills among the students.

METHOD

Participants

An online survey was sent to 554 students in engineering and applied engineering at Reykjavik University. In total 271 (49%) answered, 193 (71%) engineering students and 77 (29%) applied engineering students, 173 (64%) male and 98 (36%) female. The BSc engineering program is a 3-year or 6 semester's program and applied engineering is a 3.5 years or 7-semester program. Most of the participants, or 213 (78%), were in semester 1-6, 34 (13%) had spent more than 6 semesters on their study and 24 (9%) were master students. The participants' average age was 24.7 years, ranging between 19 and 44 years.

Measures

The online survey, consisting of eleven questions, was designed for the purpose of the study. Four background questions identifying the participant's gender, age, line of study and semester and seven questions concerning the participant's experience with computers and choice of line of study. The seven questions were the following:

- Two questions about the participants computer use in elementary and upper secondary school: "How did you primarily use computers in primary school?" and "How did you use computers in upper secondary school?". Each question had five answering possibilities: "For studying", "Playing computer games", "For programming", "Working with hardware", and "Something else". The participant could select one answer.
- One question about the participants' computer skills before they entered university: "How much computer skills do you consider you had before you started your study?" This question was rated on a five point Likert scale, ranging between "Very good" and "Very little". The term computer skills was not defined in the questionnaire and the participant could select one answer.
- One question about the reasons for choosing the present line of study: "Why did you chose your line of study?". Ten answering options were given and the participant was instructed to select the three most relevant for him/her. The participant could select three answers without categorise them.
- One question about the age of the participant when he/she got interested in his/her present line of study at university: "When did you first get interested in your subject?", with the possibility of choosing four age categories, younger than 14, 15-18, 19-22 and older than 22.
- One question asked if the participant had considered choosing another line of study at university: "Did you consider to choose another subject?". This question was rated with "Yes" or "No", and If yes, then what line of study?

Procedure

The survey was put online in the system Free Online Surveys (https://freeonlinesurveys.com). A link was sent to the participant by e-mail on the 2th November 2017 and reminders on the 15th November and the 30th of November. The survey was closed on the 11th January 2018. Data analysis was carried out in Excel and the Statistical Package for the Social Sciences (SPSS).

RESULTS

Table 1 describes the participants' reasons for choosing their present line of study, i.e. engineering and applied engineering. Of the ten options given, five differed between the males and the females. More males than females chose because they considered engineering and applied engineering interesting professions and they were interested in computers. On the other hand, more females than males mentioned interest in math and science, that they did well in science in upper secondary school and that they just wanted to try.

Table 1. The participants' reason for selecting engineering and applied engineering, according to gender.

	Male	Female	
	Yes N (%)	Yes N (%)	Chi-square
Interesting profession	108 (62.4)	37 (37.8)	15.31***
Good employment outlook	84 (48.6)	47 (48.0)	0.01
Good salary	82 (47.4)	45 (45.9)	0.05
Interested in math and science	51 (29.5)	54 (55.1)	17.30 ***
Interested in computers	25 (14.5)	1 (1.0)	13.01***
Did well in science in upper secondary school	30 (17.3)	36 (36.7)	12.77***
I just wanted to try	11 (6.4)	18 (18.4)	9.44 ***
Diversified profession	40 (23.1)	20 (20.4)	0.27
It has never been anything else	11 (6.4)	4 (4.1)	0.62
I was encouraged by others	13 (7.5)	6 (6.1)	0.19

*** p<0.001

When the participants were asked if they had considered selecting another profession than engineering or applied engineering, 98 (57%) males and 63 (64%) females said yes. Twenty-seven said they had considered business, 13 males and 14 females, 23 medicine, 10 males and 13 females, 9 computer science, all males, five physics, all males and five psychology, all of them female. Nine males also mentioned geology (2), law (2), mathematic (1), sports science (1), history (1), architecture (1), chemistry (1), literature (1) and aeronautics (1). The females mentioned also mathematic (5), nursing (2), pharmacy (2), art (2), music (1), architecture (1), molecular biology (1) and nutrition (1).

Table 2 shows that most participants got interested in their field of study when they were between 15 and 22 years old. Of interest is though, that more of the males claimed they developed their interest when they were teenagers and after 22 years of age (13 and 23 per cent, respectively), than the females (6 and 13 per cent, respectively). More females than males reported that they got interested when they were between 15-22 years old, or 81% versus 64% of the males.

Table 2. Age when participants got interested in their field of study.

	Males N (%)	Females N (%)	Total N (%)
14 years and younger	23 (13)	6 (6)	29 (11)
15-18 years old	52 (30)	41 (42)	93 (34)
19-22 years old	59 (34)	38 (39)	97 (36)
22 years and older	39 (23)	13 (13)	52 (19)
	173 (64)	98 (36)	271 (100)
	Chi-square 8.725*		

*p<0.05

Table 3 shows the difference between the genders in computer use in compulsory and upper secondary education. Males reported significantly more often having used computers for playing computer games in compulsory education, but girls for studying. Only two participants reported having used computers for programming, one male and one female and only three participants, all males, claimed having worked with hardware. Table 3 shows that the pattern is the same in upper secondary schools, males playing computer games and females are using computers for studying. Only one male participant reported having used computers for programming in upper secondary education, and five participants, four males and one female, claimed having worked with hardware.

Table 3 Participants' primarily use of computers in compulsory- and upper secondary education.

	Compulsory education		Upper secondary education	
	Males N (%)	Females N (%)	Males N (%)	Females N (%)
For studying	30 (19.4)	34 (40.0)	87 (56.1)	91 (96.8)
Play computer games	125 (80.6)	51 (60.0)	68 (43.9)	3 (3.2)
Chi-square	11.965***		45.504***	

***p<.001

Twenty-eight participants, 15 males and 13 females, reported using computers in compulsory education for something else than was asked about. Ten of the male participants claimed they had not at all used computers in compulsory education, two claimed they used computers to learn keyboarding, two said they used computers to watch TV series, and one for surfing on the Internet. Four of the female participants reported no computer use in compulsory education, two claimed they used computers for social networking, two for MSN, and five claimed they used computers for making music, learning word processing and watching TV series.

Eleven participants, 8 males and 3 females, reported using computers in upper secondary school for something else than was asked about. Two males claimed they did not use computers at all, one said he hardly used computers and five reported programming, social media, watching TV series, and writing reports. The three females all claimed they used computers in upper secondary education for social media.

Figure 1 shows that 49% (83) of the males and 26% (26) of the females considered their computer skills to be good or very good when they started their current study at university.

Independent samples T-test showed significant difference between the genders on this variable, males scoring 2.5 (SD=0.9) and females 2.8 (SD=0.8) (t-value 2.952, $p<0.01$).

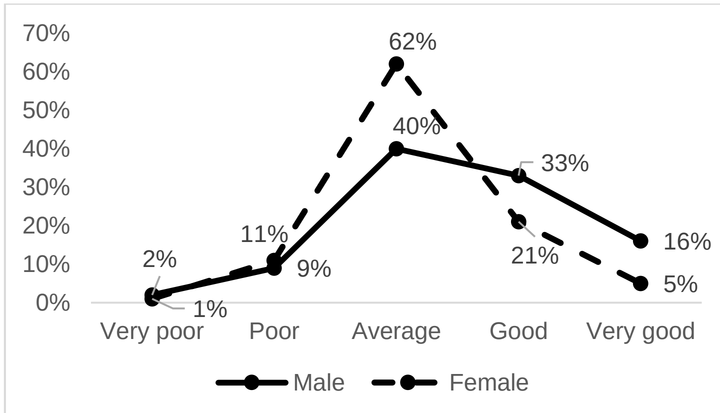

Figure 1 The participants' computer skills before they started studying engineering and applied engineering at university

DISCUSSION

The main research question in the present study was: *Is there a gender difference in students' motive for choosing to study engineering?.* About half of the participants claimed that good employment opportunities and good salaries were the two main reasons, but gender differences were apparent. The male participants reported an interesting profession, but the female participants claimed it was because of their interest in mathematics and science that they choose engineering. More female participants also claimed that doing well in science in upper secondary school was a reason for they choice of study.

These findings are not in line with previous studies, where females are not considered to have much interest in STEM subjects, e.g. because of lack of interest in math and science although they are doing well in these subjects. Anyhow, Ertl, Luttenberger, & Paechter (2017) have pointed out that females in STEM subjects have overcome many barriers like negative stereotypes and might mostly be driven by their interest in math, science and computers. This implies that in order to get more females into STEM studies we need to foster their interest in those fields especially in high school (Sadler et al., 2012). With reference to the literature, we need to develop stereotypes that are more positive, change the teaching methods and the learning environment and introduce more STEM subjects earlier in schools.

Although few participants said that they choose engineering just because they wanted to try it, the gender difference is surprising, why do more females give that reason than males? Was it because they perceived engineering as a male subject or because or are they more for trying something new? This has to be studied further.

Interestingly, the findings revealed gender differences when students developed interest in their field of study, e.g. engineering or applied engineering. Most students claimed they got interested in engineering between 15 and 22 years old, especially the female participants. This wakes the question at what age it would be realistic to introduce engineering as a subject to female students and if it should be different from the male students. Although there are many other influencing factors to bear in mind when finding the right age to introduce a subject to students it is of importance to consider which is the best age and it could be useful to probe this finding further.

It is also of interest how late students get interested in their field of study and how many of them have considered other profession as business and medicine. Part of this can be described by how late students go to university in Iceland, as the normal age for finishing the matriculation exam has been 20 years of age (the study has now been shortened by a year).

Two other research questions were: *Is there a gender difference in computer use in education prior to university?* and *Is there a gender difference in self-reported computer skills among engineering students?* This study shows a marked gender different in self-reported computer use and computer skills, both in compulsory and upper secondary school education, or before the participants started their current studies. The male participants used computers mainly for playing games and the female participants for studying. In addition, the male participants reported better computer skills than the females and there was a gender difference when they claimed interested in computers to be the main reason for choosing engineering study. This is in line with the literature. How these gender differences influence students' carrier choices is not clear from this study, but as Paino & Renzulli (2013) point out, use of computers in education can impact academic performances and thus may support better technology self-efficacy among students.

CONCLUSIONS

This study indicates a gender difference in the reason for choosing to study engineering where females reported more frequently being interested in math and science and how well they did in science in upper secondary school as the main influencing factor. It also indicates that females decide older alter what subject to study at university. This could guide us in trying to attract students to engineering studies by foster female interest in STEM at an early age and introduce engineering to them.

It is important for both young men and women to realize that they do not have to conform to a certain type or personality characteristic to learn a particular subject; you do not have to be a nerd to study STEM. We have to make sure that that the schools and workplaces do not support stereotypes that scare off either gender. When it comes to other influencing factors as family, community and role models, media and culture, we come to the influence of society as whole, the cultural environment. The media and the entertaining industry plays a big role in young person's life today through smart phones and other smart equipment and there is an opportunity to change the stereotypes.

The CDIO Standard 1 (program philosophy) shows the importance of the cultural framework and environment for engineering education. The literature emphasises that the learning environment should avoid negative stereotypes of STEM subjects, which wakes the question if this topic should be added into the Standard 1. The CDIO Standards 7 and 8 (Integrated Learning Experiences and Active Learning) emphasise the importance of active teaching and learning and use of miscellaneous teaching methods. The literature points out that different teaching method may apply differently to males and females and this again wakes the question whether this topic should be added into the CDIO standards to emphasize that we need to ensure that engineering education is attractive for both genders.

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BIOGRAPHICAL INFORMATION

Asrun Matthiasdottir PhD, is an Assistant Professor in the School of Science and Engineering at Reykjavik University. Her research interests are in equality in education, the use of information and communication technology (ICT) in education in a wide context and the use of new teaching methods in science education to improve the quality of education.

Corresponding author

Asrun Matthiasdottir
Reykjavik University
Menntavegur 1
101 Reykjavik
Iceland
asrun@ru.is

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ENGINEERING EDUCATION: ARE EFFORTS IN SOTL REACHING THE ENGINEERING CLASSROOM?

Nancy Nelson

Electronic Systems Engineering, Conestoga ITAL & Engineering Education, University of Calgary

Robert Brennan

Mechanical & Manufacturing Engineering, University of Calgary

ABSTRACT

If you were to walk into almost any engineering classroom today it would be difficult for you to differentiate it from one in 2000, 1980 or even 1960. The technology and tools may be different, but the delivery largely remains teacher-directed and lecture-based. While the Scholarship of Teaching and Learning (SoTL) is widely supported at most post-secondary institutions, there is little evidence that this scholarly work is reaching the engineering classroom. Similar work in Discipline-Based Education Research (DBER) also appears to be going unimplemented. This descriptive study examines the level to which engineering faculty at Canadian institutions are accessing and applying the findings of SoTL and DBER work within their classrooms.

KEYWORDS

SoTL, engineering education, Discipline-Based Education Research (DBER), evidence-based teaching, Standards: 7, 8, 10, 11

INTRODUCTION

Most undergraduate engineering students experience learning in exactly the same way as did generations of graduates before them. Even with evidence-based methodologies, tools, and technologies, the traditional, teacher-centered, lecture-based classroom still prevails. At the same time, institutional teaching and learning centres support both the scholarship of teaching and learning and the practicalities of day-to-day teaching.

Many researchers have tried to understand this dichotomy between theory and practice. There are myriad opportunities for instructors to learn about and implement the findings of both the Scholarship of Teaching and Learning (SoTL) and Discipline-Based Education Research (DBER), but there is little evidence that this scholarly work is making its way into engineering classrooms. This paper reports the findings of a national survey that measures the level to which current engineering faculty at Canadian institutions are accessing and applying the findings of SoTL and DBER work within their classrooms.

BACKGROUND

Engineering in Canada pre-dates its 1867 confederation. Engineers Canada, the national organization of the provincial and territorial associations that regulates the practice of engineering in Canada, defines the "practice of engineering" as "any act of planning, designing, composing, evaluating, advising, reporting, directing or supervising, or managing any of the foregoing, that requires the application of engineering principles and that concerns the safeguarding of life, health, property, economic interests, the public welfare or the environment" (*National guideline on the practice of engineering in Canada*, 2012). Early civilian and military engineering helped establish the country's transportation, fortification, and infrastructure systems. It took about 30 years from the creation of the first engineering organization in 1886, until all Canadian provinces at the time had enacted Professional Engineering Acts to regulate the profession. At the time this included civil, mechanical, chemical, electrical, and mining engineers (Devita, 2012). Engineers Canada is now comprised of 12 engineering regulators that license the country's 290,000 practicing engineers in both traditional and non-traditional disciplines as diverse as aerospace, geomatics, industrial, naval, petroleum, and software engineering.

Engineering Education

While engineering practice itself was integral to the colonization of Canada, attempts at formalizing engineering education did not get underway until the 1850s. The first engineering course, two and a half months in duration, was offered at King's College in New Brunswick (now University of New Brunswick) in 1854 with 26 students enrolled. By the turn of the 20th century there were six engineering schools across the country offering programs in civil, electrical, mining, and mechanical (Morris, 1986). Now, almost two decades into the 21st century, there are 43 schools offering 281 accredited engineering programs.

Accreditation of Canadian engineering schools began in 1965. This process, undertaken by the Canadian Engineering Accreditation Board (CEAB), a committee of Engineers Canada, ensures that graduates of engineering programs meet the high standards necessary to become licensed professional engineers. Initially an accreditation review examined the depth and breadth of the science, mathematics, engineering science, engineering design and complementary studies within a program. In 2015 this was expanded to include an assessment of 12 graduate attributes encompassing the professional body of knowledge (knowledge base, problem analysis, investigation, design, and engineering tools), employability skills (individual and team work, communication skills, life-long learning), and professional responsibilities (impact on society, ethics and equality, economics and project management, and professionalism) required of a professional engineer (Nelson, 2014). Programs are also expected to demonstrate ongoing quality through implementation of a continual improvement plan.

Graduate attributes have engineering educators looking for ways to make undergraduate engineering programs more authentic and student-centered, and create an environment where students are actively engaged in, and accountable for, a deeper form of learning. These efforts are happening at all levels from international, to institutional, to individual.

Movements such as CDIO (Conceive-Design-Implement-Operate) suggest that conceptual-change instruction, where learning happens through a series of authentic, integrated learning experiences some of which are experiential, will teach both the body of knowledge and skills required to be a professional engineer (Crawley, Malmqvist, Östlund, & Brodeur, 2014). Learning experiences like this challenge students to construct their own knowledge and confront their misconceptions. Most Canadian engineering programs are increasing the number of design-based project courses to help students recognize the integrative and cross-disciplinary nature of engineering projects. Other programs include project- and/or problem-based learning as part of their curriculum (Woods, 1996; Nelson, 2014), and some have fully transitioned to project-based and problem-based learning (Gonzalez-Rubio, Khoumsi, Dubois, & Trovao, 2016). These are all steps toward a more authentic undergraduate engineering experience, but as the CDIO vision suggests, reform in engineering education requires the review of four intertwined areas: the overall curriculum and course content, the learning environment, the way content is taught, and assessment and evaluation of the program outcomes (Crawley et al., 2014). One of the biggest challenges in this effort is to overcome the situational barriers and constraints that affect whether instructors can effectively implement the findings of research in engineering education (Henderson & Dancy, 2007).

Engineering Education Research (EER)

A review of the major shifts in engineering education was commissioned by the Institute for Electrical and Electronic Engineers (IEEE) on its 100th anniversary (Froyd, Wankat, & Smith, 2012). It reported five shifts: (1) from a hands-on, practical approach to an engineering science and analytical emphasis, (2) to outcomes-based education and accreditation, (3) toward engineering design, (4) to applying education, learning, and social-behavioral sciences research, and (5) to the integration of technology in education. The first two shifts have occurred, while the remaining three are still in progress. Of interest to this paper is the fourth shift, in particular the application of interdisciplinary research methods to engineering education.

Although formalized research in engineering education is still considered to be in its infancy (Borrego, Foster, & Froyd, 2014), engineering educators have always been committed to improving instruction at the classroom level. Formed in 1893, the Society for the Promotion of Engineering Education (SPEE) was the first official organization in North America to dedicate itself to the noble yet sometimes difficult task of promoting high quality and effecting change in engineering education (Reynolds & Seely, 1993). In 1946 this organization became the American Society for Engineering Education (ASEE) which is still committed to furthering education in engineering and engineering technology. In 2003 its quarterly scholarly publication, the Journal of Engineering Education (JEE), was the first journal dedicated solely to the publication of peer-reviewed research in engineering education.

Similar organizations dedicated to engineering education research developed around the world, including in Canada. The Canadian Engineering Education Association (CEEA) formed in 2010 integrating the efforts of the Canadian Design Engineering Network (CDEN) and the Canadian Congress on Engineering Education (C2E2) (Yellowley, Venter, & Salustri, 2001). Its mission is to “enhance the competence and relevance of graduates from Canadian Engineering schools through continuous improvement in engineering education and design education” (CEEA, 2018). While CEEA does not currently have a publication to share the findings reported at its annual conference, as of 2018 it will separate its proceedings into those that are reporting peer-reviewed, research-informed findings, and those that report general practices such as innovations and experiences in the classroom.

Engineering education research tends to be published in two types of journals: those dedicated to SoTL, and those dedicated to DBER.
Scholarship of Teaching and Learning (SoTL)

The Scholarship of Teaching was first introduced by Ernest Boyer in 1990 (Boyer, 1990) to help bring focus to the importance of teaching as part of the appointment, promotion, and tenure of academic staff. Over the years this evolved into the Scholarship of Teaching and Learning as researchers emphasized that their work focused on student learning. SoTL studies are typically descriptive and focus on innovation in one's own higher education classroom (Dolan et al., 2017). Its five principles of good practice clarify that SoTL research is (1) inquiry into student learning, (2) grounded in context, (3) methodologically sound, (4) conducted in partnership with students, and (5) appropriately public (Felten, 2013).

SoTL efforts vary across Canada. While disciplinary research is funded nationally, pedagogical research falls under the jurisdiction of provincial governments and funding can be very difficult to acquire. Many institutions have established strong SoTL programs to support their faculty, and graduate students appreciate and participate in SoTL research. The Society for Teaching and Learning in Higher Education (STLHE) identified SoTL as the first of its four pillars or strategic directions, and in 2009 established a partnership with the International Society for the Scholarship of Teaching and Learning (ISSoTL) to acknowledge their common goals around SoTL. In 2010 STLHE launched the Canadian Journal for the Scholarship of Teaching and Learning (CJ SoTL), the first Canadian open access, peer-reviewed national venue for transdisciplinary SoTL research (Simmons & Poole, 2016).

Provincial and institutional studies have been done to measure the involvement of university faculty in SoTL activities. Instructors reported that their teaching knowledge came mostly through practice, learning by doing, or consulting with colleagues. They identified that there is disparity between merits of research and teaching, and that traditional research pays off in status and reputation. Most of those who reported doing classroom research indicated they used the results to modify their own teaching. Many of these instructors who were doing SoTL work felt their efforts had little or no visibility to their colleagues unless it was published in a high impact peer-reviewed venue (Britnell et al., 2010; Wuetherick, Yu, & Greer, 2016).

Discipline-Based Education Research (DBER)

Discipline-Based Education Research is a term used primarily by post-secondary educators in Science, Technology, Engineering, and Mathematics (STEM). It is a form of scholarship of teaching and learning that requires deep knowledge of the disciplinary content and its practices, in addition to the expertise needed to conduct education research (Singer, Neilsen, & Schweingruber, 2012). DBER is typically conducted in one of the following areas: engineering epistemologies (ways of thinking and knowing within the discipline), learning mechanisms (developing knowledge and competencies), learning systems (culture, infrastructure, and epistemology of educators), diversity and inclusivity, assessment, or design.

Initial DBER efforts typically involve identifying incorrect understandings and misconceptions, and identifying those that are most difficult to change. It then extends to the identification of instructional strategies or techniques that help students move beyond the troublesome concepts and ultimately improved learning.

In Canada STLHE recognizes DBER and its discipline-specific emphasis as a parallel form of educational research and suggests that each community has much to offer to the other. The findings of engineering-related DBER are typically presented and published through its own Engineering Education Research (EER) organizations such as the American Society for Engineering Education (ASEE) and CEEA.

The differences between doing discipline-specific research and EER present distinctive challenges for STEM educators moving into the world of SoTL or DBER. First they must be prepared to engage with the literature both within and beyond their discipline. They must learn and use a new vernacular, and move from a teacher-centered focus where they consider the importance of their teaching to a more student-centered approach where the focus is on student learning. They must use different research methods, analyze their data in different ways, present to a different audience, and finally accept that EER, as a form of SoTL, requires one to consider theoretical frameworks and accept applicability as a goal of rigorous research. (Krefting, 1991; Streveler, Borrego, & Smith, 2007; Tierney, 2017).

Dissemination of SoTL and DBER

There are four levels of rigor at which an instructor can engage in education-related inquiry: excellent teaching, scholarly teaching, scholarship of teaching, and rigorous research (Borrego, 2007). Ideally, every instructor teaching in an undergraduate engineering program is involved in at least the first level which means bringing excellent content and evidence-based instructional strategies to the classroom. Unfortunately the research shows that a gap exists between the research and the classroom (Henderson & Dancy, 2007) (Singer et al., 2012) (Froyd, Borrego, Cutler, Henderson, & Prince, 2013) (McLaren & Kenny, 2015) (Dancy, Henderson, & Turpen, 2016).

The results are shared with educators through conferences, workshops, and talks, but the actual Research-Based Instructional Strategies (RBIS) are not making their way into the day to day classroom. Some instructors experiment with RBIS but find that they don't work in their particular environment. Some of the more commonly identified reasons for discontinuing or not attempting to integrate RBIS are institutional expectations around the balance of research, teaching, and service, lack of departmental or institutional support, and situational constraints and barriers such as student resistance, available time to cover content, and increased preparation time.

Bridging this gap between research and practice requires four key things: (1) the work must be consistent with research on motivating adult learners, (2) effort must be placed on changing faculty conceptions about teaching and learning, (3) the cultural and organizational norms must be recognized as part of a strategic move toward scholarly teaching and/or rigorous EER, and (4) action must be taken to address the barriers to change in teaching practice (Singer et al., 2012).

In order to establish a starting point for change, this research examines the level to which engineering faculty teaching in accredited engineering programs across Canadian institutions are accessing and applying the findings of SoTL and DBER work within their classrooms.

PROCESS

Early in 2018 engineering educators were asked to complete an online survey about the current state of undergraduate engineering education in Canada. This survey explored the types and balance of research, teaching, and service engineering educators do, the characteristics of the teaching and learning environment, and perceptions about the learners sitting in our classrooms.

A subset of this survey explored the instructors' engagement with SoTL and/or DBER looking for four key facets: (1) how informed they are about SoTL/DBER, (2) how important evidence-based teaching is in their own practice, (3) how interested they are in applying RBIS in their classrooms, and (4) how involved they are in doing SoTL/DBER research. This portion of the broader survey is used for this research.

Methodology

3376 participants were invited by e-mail to complete an online survey entitled A Snapshot of Canadian Engineering Education. Some institutions provided the researchers with a mailing list of their faculty, others were contacted directly via the e-mail posted on their departmental web site, and a third group were contacted through their on-campus member of GANet, an online network of engineering faculty and staff involved in the engineering accreditation process. There were no incentives provided for instructors to complete the survey.

The survey, modeled after the Higher Education Quality Council of Ontario (HEQCO) survey on faculty engagement in teaching development activities (Britnell et al., 2010), collected basic demographic data including the name of the institution, and the number of years they had been teaching. It had two major sections: (1) Institutional Expectations that examined the balance and types of service, research, and teaching, and (2) Undergraduate Engineering Education that captures what the current undergraduate learning experience is like.

Data Analysis

224 of the 3376 engineering educators (6.6%) participated in this research study. There was representation from 74.4% of the institutions that offer accredited engineering programs. 17.9% were new instructors who had been teaching fewer than five years, 42.9% were mid-career faculty who had been teaching between five and 15 years, and the remaining 39.3% were seasoned instructors with more than 15 years.

There is a possibility that the findings of this survey have a bias associated with non-response. Those who chose to complete the survey may have different views from those who did not. This may limit the generality of the results of this study (Sax, Gilmartin, & Bryant, 2003; Adams & Lawrence, 2015). It is also not known to what degree respondents were encouraged to participate by their institution's administration or what other factors may have contributed to their response or non-response. As a result, the following findings should be considered with caution.

Five of the 28 variables available in the full data set were analyzed to examine the instructors' engagement with EER. Each of these five are related to the instructors' teaching practice: (1) how they maintain currency, (2) frequency of participation in teaching related professional development activities, (3) how often they reference SoTL or DBER resources, (4) participation in DBER or SoTL research, and (5) willingness to use or access a digital resource that delivers short concise abstracts of engineering education related research findings with associated application notes and examples.

Maintaining Currency

Question 15 asked participants to indicate whether or not they used 10 different ways of staying current in their teaching practice. The percentage of instructors who indicated using each of the methods is shown in Figure 1.

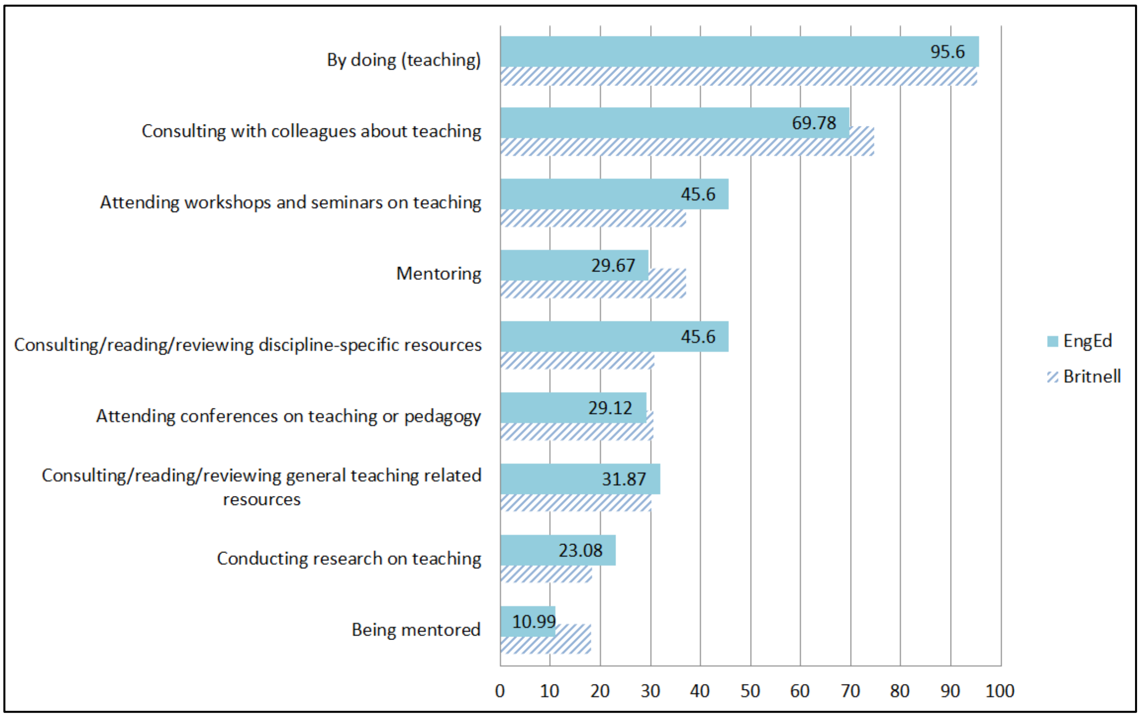

Figure 1: Method for Staying Current in Teaching

The most commonly used technique that educators use to stay current is learning by doing (95.6%). This is followed by consulting with colleagues (69.8%). The least used techniques are conducting research on teaching (23.1%) and being mentored (11.0%). The three items specifically related to SoTL and DBER indicate that 45.6% are interested in learning about teaching and learning by attending workshops or seminars, that the teaching practice of 31.9% of the instructors is informed by published education-related research, and that 23.1% are involved in DBER or SoTL research.

The most noticeable differences between these results and those of the 2010 Ontario study of post-secondary educators (Britnell et al., 2010) are in the almost 15% increase in the percentage of instructors who are informing their teaching practice by consulting, reading, and/or reviewing discipline-specific resources, the 8.4% increase in the percentage of instructors attending workshops and seminars on teaching, and the just over 7% decrease in both mentoring and being mentored.

Participation in Teaching-Related Professional Development

Question 18 asked participants to indicate whether or not they participated in five different forms of teaching-related professional development (PD). The percentage of instructors that indicated participating in each form of PD is shown in Figure 2. The majority of instructors (62.6%) are discussing teaching and learning with their colleagues at least monthly and are doing critical self-reflection at least once a month (53.1%). Only a tenth (10.1%) indicated that they regularly use the services offered by their teaching and learning centre.

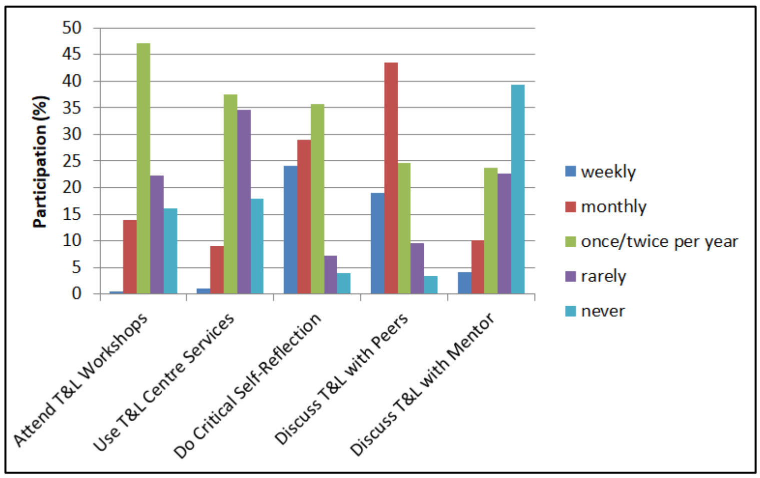

Figure 2: Participation in teaching-related professional development

These results show a decrease in PD activities compared to the 2010 Ontario study of post-secondary educators (Britnell et al., 2010) where 73.5% instructors indicated they discussed teaching and learning with their colleagues at least monthly and (60.9%) did critical self-reflection at least once a month.

Use of SoTL and/or DBER Resources

Question 21 asked participants to indicate how often they read general and discipline-specific literature related to teaching. Figure 3 shows that the minority of instructors (46.2%) are infrequent or non-readers of general literature related to teaching and 42.5% are infrequent or non-readers of discipline-specific literature related to teaching.

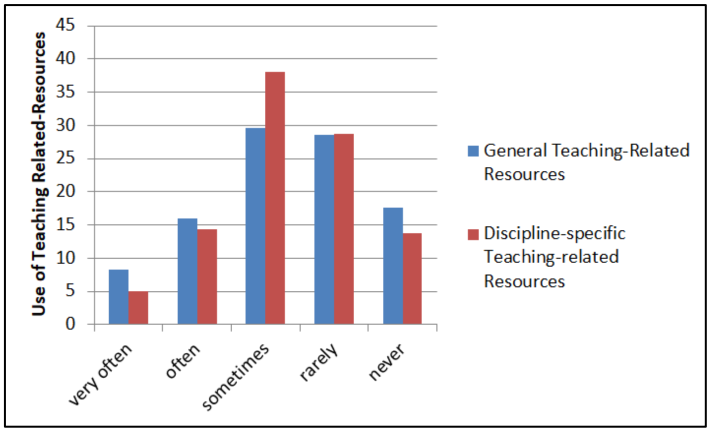

Figure 3 - Use of Teaching-Related Resources

These results show an improvement in how often instructors use teaching-related resources compared to the 2010 Ontario study of post-secondary educators (Britnell et al., 2010) where 65.3% were infrequent or non-readers of general literature related to teaching and (63.1%) were infrequent or non-readers of discipline-specific literature related to teaching.

Participation in DBER or SoTL Research

Question 24 asked participants to indicate whether or not they had done any formal or informal research related to the teaching and/or learning in their classroom. Figure 4 shows the types of classroom-related research reported by the 32.8% of overall participants who indicated they had done this type of formal or informal research. 36.1% of this research activity had research ethics board approval. The most commonly reported types were associated with general aspect of teaching and learning such as surveys of student satisfaction, and student behaviour (36.1%). The majority of these research findings were used for effecting change in the instructors' own practice (52.5%). 37.7% of the findings were presented at conferences and 9.8% published in journals. 81.0% of instructors reported that these findings did results in some level of change to their classroom practices.

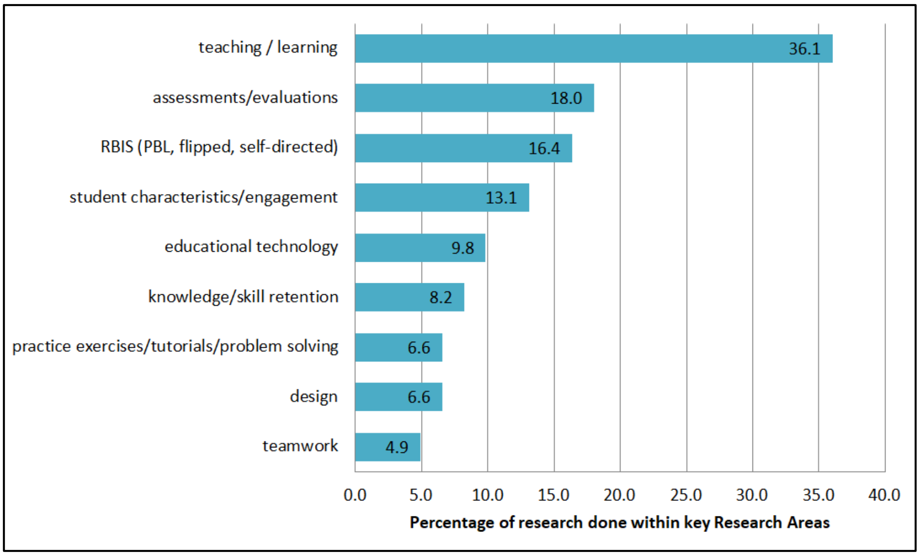

Figure 4: Types of Classroom-related Research done by Canadian Engineering Educators

Willingness to Receive SoTL and DBER Resources

Question 27 asked participants to indicate how likely they would be to use or access a digital resource that delivers short concise abstracts of engineering education related research findings with associated application notes and examples. Figure 5 shows that the majority of instructors (59.4%) are likely to access or use this type of resource.

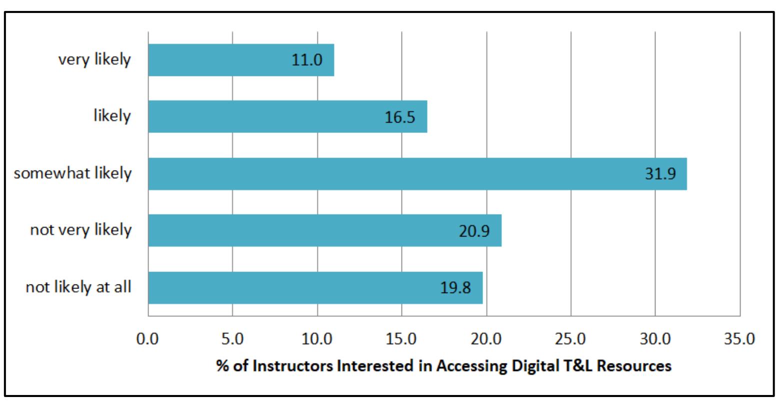

Figure 5: Willingness to Receive SoTL and DBER Resources

RESULTS

Grouping different aspects of the analyzed data helps identify just how engaged instructors are with SoTL and/or DBER in four key area: (1) how informed they are about SoTL/DBER, (2) how important good teaching is their own practice, (3) how interested they are in applying RBIS in their classrooms, and (4) how involved they are in doing SoTL/DBER research. Table 1 shows the questions and results used to calculate a strength factor for each of the four key areas. This strength factor is calculated as the mean of the means for each of the applicable measures of EER engagement. Measures based on percentages of a subset of data are reported, but not included in the strength factor.

Table 1: Calculation of Strength Factor for Instructor Engagement with SoTL and DEBR

Informed about SoTL and DBER

	Maintaining Currency			PD		Use of Resources		Participation		
Questions	15c	15f	15g	18a	18b	21a	21b	24a	24d	* percentage of a subset of data
	workshops	teaching-related conferences	research	workshops	TLC services	general teaching resources	discipline-specific teaching resources	own research	ethics?	
% participation	45.6	29.1	31.9	61.7	47.5	53.8	57.5	32.8	36.1	STRENGTH FACTOR
Mean	35.5			54.6		55.6		32.8	not applicable*	45
Std Deviation	8.8			10.0		2.6				

Importance of evidence-based teaching

	Maintaining Currency			PD				Use of Resources		Participation	Willingness	
Questions	15b	15c	15f	18a	18b	18d	18e	21a	21b	24a	27	
	colleagues	workshops	teaching-related conferences	workshops	TLC services	colleagues	mentor	general teaching resources	discipline-specific teaching resources	own research	easy access to digital resource	
% participation	69.8	45.6	29.1	61.7	47.5	87.2	38.1	53.8	57.5	32.8	59.3	STRENGTH FACTOR
Mean	48.2			58.6				55.6		32.8	59.3	51
Std Deviation	20.5			21.4				2.6				

Interest in applying SoTL and DBER findings in own teaching practice

	Maintaining Currency			PD		Use of Resources		Participation	Willingness	
Questions	15c	15f	15g	18a	18b	21a	21b	24a	27	
	workshops	teaching-related conferences	research	workshops	TLC services	general teaching resources	discipline-specific teaching resources	own research	easy access to digital resource	
% participation	45.6	29.1	31.9	61.7	47.5	53.8	57.5	32.8	59.3	STRENGTH FACTOR
Mean	35.5			54.6		55.6		32.8	59.3	45
Std Deviation	8.8			10.0		2.6				

Involvement with SoTL and DBER

	Participation				
Questions	24a	24b	24c	24d	
	own research	caused change?	shared with community?	ethics?	
% participation	32.8	81.0	47.5	36.1	STRENGTH FACTOR
Mean	32.8	not applicable*			33
Std Deviation					

Informed about SoTL and DBER

Table 1 shows that engineering instructors across Canada are reasonably well informed about SoTL and DBER, as well as ways the research can improve their teaching practice. While their overall use of education-related research to maintain currency in their teaching is quite low (*M* = 35.5 *SD* = 8.8), they are participating in professional development activities (*M* = 54.6 *SD* = 10.0) and accessing teaching resources (*M* = 55.6, *SD* = 2.6) that can help inform their teaching practice. 32.8% indicate they are already conducting education-related research, although only a small portion of that research has received approval from an ethics board (36.1%). A middling strength factor of 45 indicates a reasonable level of engagement with SoTL and DBER at the information level, but there is opportunity for improvement.

Importance of evidence-based teaching in own practice

Engineering instructors across Canada seem to recognize the value of evidence-based teaching in their own practice. Discussing teaching and learning related issues and challenges with their colleagues, and attending teaching-related workshops and conferences (*M* = 48.2 *SD* = 20.5) show an interest in quality teaching. Their level of participation in professional development activities including those offered by their institution's teaching and learning centre (*M* = 58.6 *SD* = 21.4) and access of teaching resources (*M* = 55.6, *SD* = 2.6) indicates that about half recognize how the findings of teaching-related research can help guide their teaching practice. 32.8% indicate they are already conducting education-related research, and 59.3% report they would willingly access a digital resource that delivers, evidence-based EER that included abstracts, application notes, and examples. A moderate strength factor of 51 indicates a reasonable understanding of the importance of SoTL and DBER, but that there is opportunity for improvement.

Interest in applying SoTL and DBER findings in own teaching practice

Engineering instructors across Canada seem reluctant to apply SoTL and DBER findings in their own teaching practice. While their overall use of education-related research to maintain currency in their teaching is quite low (*M* = 35.5 *SD* = 8.8), they are participating in professional development activities (*M* = 54.6 *SD* = 10.0) and accessing teaching resources (*M* = 55.6, *SD* = 2.6) that can help generate interest in transforming what happens in their classrooms. 32.8% indicate they are already conducting education-related research in order to improve the learning experience in their own classrooms. 59.3% report they would access a digital resource that delivers short concise abstracts of engineering education related research findings with associated application notes and examples on a need-to-know basis. A slightly lower strength factor of 45 highlights this juxtaposition between the instructor's low usage of EER and their willingness to explore the literature if presented in a more tangible, practical way.

Involvement with SoTL and DBER

The percentage of engineering instructors in Canada who are involved in SoTL and DBER research is quite low (32.8%), and only a small portion of that research has received ethics approval (36.1%). These instructors are using their findings to make changes in their own classrooms (81.0%) but fewer than half are making their work public (47.5%). A low strength factor of 33 indicates this reluctance to conduct rigorous EER. If institutions, departments, and programs value this type of research it may not be obvious to their instructors.

DISCUSSION

The results of this study indicate that educators in accredited engineering programs across Canada are moderately engaged in the scholarship of teaching and learning and/or discipline-specific education research. These instructors are reasonably well informed about what SoTL and DBER are, and are aware of ways in which the findings of this research can improve their teaching. They seem to recognize the value of evidence-based teaching, but seem reluctant to actually integrate it into their own practices. This concurs with the findings of studies that show evidence-based instructional strategies are making it into few classrooms. Commonly identified barriers include, but are not limited to, workload, time, institutional reward system, content coverage, student attitude, and availability of resources (Kaupp et al., 2015)(Henderson & Dancy, 2007)(Litzinger, Lattuca, Hadgraft, & Newstetter, 2011). Finding ways to eliminate or reduce these barriers could help facilitate the move toward evidence-based teaching in engineering classrooms.

This study found the percentage of instructors conducting any form of engineering education research to be quite low, with only a small portion of those doing rigorous research. This concurs with a Canadian engineering research review that shows that while less than 30% of the papers are theory-based, there is a trend toward more rigorous research (Brennan et al., 2018). In 2017 the Canadian Engineering Education Association (CEEA) established an annual Institute for Engineering Education Research (IER). The one day workshop includes the essential elements required to design and conduct ethical qualitative, quantitative, or mixed methods education-based research.

Together, these findings suggest that there is opportunity to improve engineering instructors' overall engagement with engineering education research, and that many educators are willing to implement the findings of SoTL and DBER in their classes if it can be made available to them in a tangible and practical way.

FUTURE WORK

Further studies will explore the opportunities to improve instructor engagement with EER. First would be to examine the distribution of effort specified by institutions, departments, and programs for the appointment, promotion and tenure for both professorial rank (i.e. research and teaching) and instructor rank (i.e. teaching) faculty. This could help determine the level to which they emphasize and officially recognize the importance that EER plays in the ongoing success of undergraduate engineering programs. Without this recognition it is unlikely that instructors will engage in EER beyond the current level. Research will also be done to more clearly define the barriers faced by Canadian engineering educators as they integrate EER findings into their classrooms.

In addition, an annual review of CEEA papers will help determine whether the IER affects the number Canadian publications based on rigorous engineering education research. This could be used as one indicator of the level of EER engagement within the Canadian engineering education community. It would also be interesting to compare countries with a longer history of EER (e.g. United States, Australia) with those that are relative newcomers (e.g. Canada).

Further study will also explore the types and forms of EER literature that faculty would consider most helpful should they choose to integrate the findings of SoTL and DBER into their teaching practice and/or conduct rigorous engineering education research.

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BIOGRAPHICAL INFORMATION

Nancy Nelson is Professor and Academic Coordinator of the Electronic Systems Engineering program at Conestoga College Institute of Technology and Applied Learning. She is also a Ph.D. student in Engineering Education at the Schulich School of Engineering, University of Calgary. She was awarded Engineers Canada's Medal for Distinction in Engineering Education in 2016, and the Colleges and Institutes Canada (CICan) gold award for Faculty Leadership in 2017. She is a facilitator in the College Development Educators Program for new faculty at the six colleges in South-western Ontario, and contributes regularly to engineering education initiatives in Canada.

Robert Brennan is Professor of Mechanical and Manufacturing Engineering and Head of Department (Mechanical & Manufacturing Engineering) at the Schulich School of Engineering. He has served on the Canadian Design Engineering Network (CDEN) steering committee, chaired the organizing committee for the second CDEN conference, chaired the Schulich School of Engineering's first Engineering Education Summit, served as an organizing committee member for the CIRP International Design Seminar, and is the current American Society for Engineering Education (ASEE) campus representative for the University of Calgary.

Corresponding author

Nancy Nelson
University of Calgary
40 - Research Place NW
Calgary, Alberta, Canada T2L 1Y6
nancy.nelson1@ucalgary.ca

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LESSONS LEARNED FROM STUDENT SATISFACTION SURVEYS OF CDIO PROJECT COURSES

Johan Malmqvist, Lars Almefelt

Department of Industrial & Materials Science
Chalmers University of Technology, Gothenburg, Sweden

Mattias Bingerud

Chalmers Operations Support
Chalmers University of Technology, Gothenburg, Sweden

Mikael Enelund

Department of Mechanics and Maritime Sciences
Chalmers University of Technology, Gothenburg, Sweden

ABSTRACT

The paper reports on a study of student satisfaction in CDIO project courses. The aims are to investigate if there are statistically significant differences in levels and variation of student satisfaction metrics between CDIO project courses and "traditional" courses, and to identify possible causes for these differences. The study was carried out at Chalmers University of Technology and focused on courses in its mechanical, automation and industrial design engineering programs. In these programs, about 20 CDIO project courses and 235 traditional courses are offered each year. In the study, student satisfaction and some other quantified metrics collected from Chalmers' course evaluation system are compared for the two groups of courses. Further, the paper examines in more detail selected CDIO project courses, with high and low student satisfaction ratings. The results of the study provide support for the hypothesis that there are significant differences in ratings. A number of causes are identified and discussed, including course leadership, perceived workload, assessment, and freedom to select task.

KEYWORDS

CDIO Standards 4, 5, 10, 12, Design-Implement project, Educational quality

INTRODUCTION

CDIO (Conceive-Design-Implement-Operate) project courses play a key role in realizing the most common reason for applying CDIO, namely the ambition to make engineering education more authentic. In addition, including more design and innovation is the third most common reason for universities to adopt CDIO (Malmqvist *et al*., 2015).

The student work produced in CDIO project courses is often realistic and of very high quality, for example advanced physical prototypes. It can be argued that CDIO project courses are crucial for students to demonstrate both the ability “to create, analyze and critically evaluate various technological solutions” and “to develop and design products, processes and systems while taking into account the circumstances and needs of individuals and the targets for economically, socially, and ecologically sustainable development set by the community”, as described in the learning outcomes for engineering education in the Swedish Higher Education Ordinance (Ministry of Education, 2017). In addition, results from CDIO project courses tend to impress external evaluators.

Nevertheless, we have observed that student satisfaction evaluations of the CDIO project courses that are offered at Chalmers University of Technology have not always been favorable: there has been a strong variation in ratings from strongly negative to highly positive. Furthermore, we have had the impression that this variation is stronger than for traditional, lecture-based subject-oriented courses. There are a number of possible causes for this, including variations in project assignments leading to mismatches between problem-solving needs and course contents, variations in teacher CDIO teaching competence, and variations in students’ preparedness for working in a project associated with a high degree of uncertainty. However, we have not conducted any systematic comparisons of the possible variations between student satisfaction levels in CDIO courses vs. traditional courses and its underlying causes, nor are we aware of any other such study.

Thus, this paper aims to:

- Compare student satisfaction evaluations of CDIO project courses and traditional, lecture-based, subject-oriented courses at Chalmers University of Technology, Gothenburg. The sample of courses is from Chalmers’ programs in Mechanical, Automation, and Industrial Design Engineering.
- Provide an in-depth study of CDIO project courses with very low and very high student satisfaction ratings, and investigate how success and problem factors correlate to guidelines for design of design-build-test projects (Malmqvist *et al*., 2004).

We first summarize earlier work on the topic. We then outline the research methodology applied in the paper. The results chapter contains a quantitative section based on data from course evaluation questionnaires as well as a qualitative section based on case studies of selected CDIO project courses. A discussion and conclusions wrap up the paper.

EARLIER WORK

The literature on CDIO project courses is dominated by case descriptions of a single course (see, e.g., Kontio & Lakanmaa, 2017; Van Torre & Verhaevert, 2017) or attempts to summarize experiences into guidelines for design of such courses (Malmqvist *et al*., 2004; Dym *et al*., 2005; Hermon & McCartan, 2017). This body of work typically places a high emphasis on describing student working practices, product outcomes and assessment procedures, rather than on providing and discussing evidence of the learning or satisfaction resulting from the learning activities.

Examples of papers that consider student satisfaction in CDIO project courses do exist (see, e.g., Liu & Lin, 2010; Schrey-Niemenmaa & Piironen, 2017) and report positive results. However, Helle *et al*. (2006) argue in a review paper on project-based learning that the literature on project-based learning provides mainly anecdotal evidence for its positive effects on student satisfaction, and that there are few or no serious attempts at understanding the motivational aspects of project-based learning. Nevertheless, Joyce *et al*. (2013) used student feedback to systematically transfer a course in Design and Manufacturing from traditional lecturing to a design-build-test team project. They found that if students are to engage effectively with the project they must view it as being relevant and authentic, that there is a delicate tension between students' wishes for autonomy and their wishes for supervision and, that students perceive a higher workload in project-based courses compared to traditional courses. Recently, a study performed at the Norwegian University of Science and Technology (Wallin *et al.*, 2017) that examined an interdisciplinary project course "Experts in teams", found strong variations in student satisfaction.

The study of student satisfaction in CDIO project courses is essential for understanding student motivational factors. Low student satisfaction with CDIO project courses, especially early in the education, may lead to students choosing more traditional courses towards the end of their studies, and even affect their career choices. Understanding student satisfaction is also essential for guiding quality improvement.

This paper contributes to the field by (a) studying student satisfaction in multiple CDIO project courses and by (b) connecting student satisfaction levels to underlying causes. Guidelines for design of CDIO project courses provide a multitude of possible causes.

RESEARCH METHODOLOGY

The study was based on courses from Chalmers' programs in mechanical (ME), automation (AE) and industrial design engineering (IDE). Chalmers offers 3-year Bachelor of Science and 2-year Master of Science programs in these disciplines, including 5-year Master of Science in Engineering programs delivered in a 3+2 year format.

The CDIO project courses selected for the study are listed in Table 1. The main criterion for considering a course to be a "CDIO project course" was that it to a large extent is carried out as a team-based design project. The coverage of the full CDIO cycle varies somewhat, as indicated in Table 1. (Capital letters C, D, etc. indicates a comprehensive coverage of the phase in the course project, whereas small letters c, d etc indicates a minor coverage of the phase). The CDIO project courses were then compared with all of Chalmers' courses within these programs.

The data for the study was collected from Chalmers' course evaluation system. The questionnaires in Chalmers' system are based on 11 common questions. The common questions are chosen to reflect a constructive alignment view (Biggs & Tang, 2007) on education, i.e. emphasizing learning outcomes, delivery of teaching and assessment, and to support cross-university quality enhancement. Seven of the common question are quantified on a scale 1-5, reflecting very poor-excellent, disagree completely-agree completely or similar. Four of the standard questions are free text, such as *"Is there anything that should be changed for the next round of this course, and if so: How?"* The students can also comment on the quantified questions. Further, the responsible teacher and the students can agree on adding additional questions for a certain course.

In the analysis, we first studied averages and variation for the quantified metrics. The averages of four aspects (student satisfaction, delivery of education, prior knowledge, and workload) were compared between the two sets of courses using Independent Samples T-tests.

Each test produces a p-value, which indicates the probability that the difference is random (Gosset, 1908). The standardized significance thresholds of 5%, 1% and 0.1% are used. The aims were to identify general patterns in the data and to select a subset of the CDIO courses for deeper analysis, where we also considered the free text data. As a starting point for the analysis we also had the research questions and the hypotheses of reasons for high and low student satisfaction as described in the earlier work section. Six CDIO project courses were selected for deeper analysis, based on that the courses had either very high or very low student satisfaction rating, or had been redesigned with significant changes in student satisfaction rating as a result.

Table 1. Studied CDIO project courses

Course	Program/ level	Year (1-5)	Credits (ECTS)	# students	CDIO
MMF176 Introduction to mechanical engineering	ME BSc	1	7	150	CDIo
PPU175 Integrated design and manufacturing	ME BSc	2	7.5	150	CDIo
MMF092 Machine design	ME BSc	3	7.5	50	DI
MPP126 Product development project	ME MSc	4	15	65	CDIo
PPU085 Product planning	ME MSc	4	7.5	60	Cd
TME180 Automotive engineering project	ME MSc	5	7.5	30	DIO
TME047 Chalmers Formula Student	ME MSc	4	15	30	CDIO
TME131 Project in applied mechanics	ME MSc	4	7.5	45	DIo
MMA151 Marine design project	ME MSc	5	15	20	CD
PPU171 Industry project	ME MSc	5	7.5	50	CD
SSY330 Introduction to automation and mechatronic engineering	AE BSc	1	7.5	85	DIO
SSY047 Systems engineering	AE BSc	2	7.5	85	DIo
SSY226 Design project in systems, control and mechatronics	AE MSc	5	7.5	120	DI
MPP083 Introduction to industrial design engineering	IDE BSc	1	10.5	45	CD
MMF274 User oriented design	IDE BSc	2	7.5	45	CDI
MMT015 Product requirements engineering	IDE BSc	2	7.5	45	CD
PPU032 User studies - Understanding the user and its requirements	IDE BSc	3	7.5	45	Cd
PPU095 Project industrial design engineering	IDE MSc	4	15	45	CDIO
PPU195 Product development project	ME & IDE BSc Eng	2	7.5	105	DIo

RESULTS

This section presents the results from the study. First the quantitative results are presented and briefly commented. Then we discuss in more depth the six case studies of CDIO project courses with very high/low student satisfaction ratings.

Quantitative results

Results per course

For the three academic years chosen for this study (2014/2015, 2015/2016 and 2016/2017), there were a total of 763 instances given of the selected courses. Out of these, 56 were deemed instances of CDIO project courses and 707 instances of other courses. Some courses were given more than once per academic year, and some were not given in one or more of the academic years considered. In the tables below, the data used for the study is listed for each of the included CDIO project courses for the academic year of 2016/2017. Table 2 provides an overview of the student satisfaction results.

It is worth noting that the courses which score lowest on student satisfaction are bachelor level courses, perhaps hinting at the need for students to have a solid foundation before undertaking CDIO project courses.

Table 2. Overview of data – BSc courses in white, MSc courses in gray

Course	Satisfaction 16/17		Delivery of education 16/17		Prior knowledge 16/17		Workload 16/17	
	Mean	St.dev.	Mean	St.dev	Mean	St.dev	Mean	St.dev
TME047 Chalmers formula student	4.71	0.61	4.50	0.65	4.00	0.96	4.43	0.94
MMT015 Product requirements engineering	4.43	0.59	4.48	0.73	4.83	0.39	3.45	0.67
MPP126 Product development project	4.38	0.82	4.25	0.68	4.57	0.59	3.88	0.74
SSY330 Introduction to automation and mechatronics	4.28	0.85	4.03	1.00	4.28	0.89	3.31	0.64
TME131 Project in applied mechanics	4.27	0.88	3.73	1.16	4.40	0.74	4.07	0.88
MMF092 Machine design	4.14	0.79	3.95	0.94	4.50	0.69	3.62	0.67
PPU095 Project industrial design engineering	4.14	1.23	3.00	1.30	4.86	0.36	3.36	0.50
PPU032 User studies – Understanding the user and its requirements	4.08	0.92	4.29	0.61	5.00	0.00	3.36	0.50
TME180 Automotive engineering project	4.08	1.00	4.42	0.67	3.83	0.94	3.17	1.03
PPU085 Product planning	3.95	0.91	3.95	0.85	4.58	0.69	3.68	0.75
MPP083 Introduction to industrial design engineering	3.92	0.84	4.08	0.80	4.27	0.92	3.42	0.76
SSY047 Systems engineering	3.66	1.41	3.22	1.24	3.94	1.24	4.34	0.75
SSY226 Design project in systems control and mechatronics	3.56	1.19	3.36	1.45	4.32	0.88	3.41	0.66
MMA151 Marine design project	3.50	0.96	3.43	1.12	4.27	0.83	3.18	1.01
PPU171 Industry project	3.43	1.45	3.79	1.12	4.79	0.43	3.85	0.80
MMF176 Introduction to mechanical engineering	3.21	1.12	2.98	1.20	4.31	0.95	3.40	0.72
MMF274 User oriented design	3.16	1.21	2.26	1.10	4.56	0.70	3.79	0.71
PPU175 Integrated design and manufacturing	2.67	1.18	3.05	1.11	4.28	1.00	4.05	0.92
PPU195 Product development project	2.48	1.12	2.57	1.16	4.19	0.98	4.43	0.68

Aggregate level results

Table 3. Student satisfaction

	N	Mean	Standard deviation (between courses)	Standard deviation (within courses), (Mean)
CDIO project courses	56	3.68	0.72	0.96
Other courses	707	3.85	0.59	0.86

The student satisfaction of courses is measured using the course survey question *"What is your overall impression of the course?"* The answer scale ranges from 1 (Very poor) to 5 (Excellent).

Student satisfaction ratings for CDIO project courses were on average 0.17 lower than for other courses on the scale from 1 to 5 (see Table 3) The p-value for the difference is 0.044, meaning it is significant at the 5% level. The standard deviation *between* courses was on average 0.13 greater for CDIO project courses. The mean standard deviation *within* courses was 0.10 greater for CDIO project courses. The p-value for the difference is 0,001, meaning it is significant at the 0.1% level.

There is thus reason to believe that student satisfaction of CDIO project courses on average is lower than for other courses, and that the range of student satisfaction (standard deviation within courses) is greater for such courses.

Table 4. Delivery of education

	N	**Mean**	**Standard deviation (between courses)**	**Standard deviation (within courses), (Mean)**
CDIO project courses	56	3.58	0.70	0.99
Other courses	707	3.86	0.65	0.90

Delivery of education in courses is measured using the course survey question *"The teaching worked well"*, to which the student can answer between 1 (Disagree completely) and 5 (Agree completely).

Student opinion on the delivery of education for CDIO project courses was on average 0.28 lower than for other courses on the scale from 1 to 5 (see Table 4). The p-value for the difference is 0.002, meaning it is significant at the 1 % level. The standard deviation *between* courses was on average 0.05 greater for CDIO project courses. The mean standard deviation *within* courses was 0.09 greater for CDIO project courses. The p-value for the difference is 0.008, meaning it is significant at the 1% level.

We can thus conclude that students' rating on the delivery of education in CDIO project courses on average is significantly lower than for other courses, and that the range of student opinions (standard deviation within courses) on delivery of education is greater in such courses.

Table 5. Prior knowledge

	N	**Mean**	**Standard deviation (between courses)**	**Standard deviation (within courses), (Mean)**
CDIO project courses	56	4.35	0.47	0.77
Other courses	707	4.26	0.37	0.85

Students' assessment of whether their prior knowledge was suitable for the course they took is measured using the course survey question *"I had enough prior knowledge to be able to follow the course"*, to which the student can answer between 1 (Disagree completely) and 5 (Agree completely).

Student ratings of their prior knowledge for CDIO project courses were on average 0.09 higher than for other courses on the scale from 1 to 5 (see Table 5). The p-value for the difference is 0.088, meaning it is *not* significant. The standard deviation *between* courses was on average 0.12 lower for CDIO project courses. The mean standard deviation *within* courses was 0.08 lower for CDIO project courses. The p-value for the difference is 0.017, meaning that the difference is significant at the 5 % level.

We can therefore assume that students' rating of whether their own prior knowledge on the subject was sufficient to follow the course does not vary significantly between CDIO project courses and other courses, but that the range of students' assessment of their prior knowledge could be slightly greater in CDIO project courses than for other courses.

Table 6. Perceived workload

	N	Mean	Standard deviation (between courses)	Standard deviation (within courses), (Mean)
CDIO project courses	56	3.67	0.47	0.74
Other courses	707	3.37	0.36	0.66

Students' assessment of perceived course workload is measured using the course survey question *"The course workload as related to the number of credits was…"* to which the student can answer between 1 (Too low) and 5 (Too high).

Students' ratings of the workload for CDIO project courses were on average 0.30 higher than for other courses (see Table 6). The p-value for the difference is 0.000, meaning it is significant on the 0.1% level. The standard deviation *between* courses was on average 0.11 greater for CDIO project courses. The mean standard deviation *within* courses was 0.08 greater for CDIO project courses. The p-value for the difference is 0.001, meaning it is significant on the 0.1% level

We can thus conclude that student ratings of the workload in CDIO project courses on average is significantly higher than for other courses, and that the range of student opinions (standard deviation within courses) on the amount of workload is greater for such courses.

Bachelor vs. master level results

Table 7. Student satisfaction in bachelor and master level CDIO project courses

			Satisfaction	
		N	**Mean**	**St. dev.**
BSc courses	**CDIO project courses**	29	3.38	0.81
	Other courses	378	3.81	0.64
MSc courses	**CDIO project courses**	27	4.00	0.40
	Other courses	329	3.89	0.53

When we disaggregate student satisfaction for CDIO project courses and other courses by bachelor or master level, certain patterns emerge (see Table 7).

The difference between CDIO project courses and other courses at master level has a p-value of 0.271, meaning it is not significant. The difference between other courses at bachelor and master level is also not significant, with a p-value of 0.104. The difference between CDIO project courses at bachelor and master level is however significant at the 0.01 % level with a p-value of 0.001. The same significance and p-value can be observed for the difference between CDIO project courses and other courses at bachelor level.

We can thus conclude that CDIO project courses on average get a higher student satisfaction rating at the master level than at the bachelor level, and that students on average are less satisfied with bachelor level CDIO project courses than other bachelor level courses. There is also no significant difference in student satisfaction between CDIO project courses and other courses at the master level, nor is there a difference in student satisfaction between other courses between the bachelor and master level.

Case studies

Below, we discuss in more detail some selected CDIO project courses. Courses with very high, low, or drastically changed student satisfaction were selected, namely:

- PPU175 Integrated design and manufacturing, Y2 ME, (low ratings)
- TME131 Project in applied mechanics, Y4 ME, (very high ratings)
- TME047 Chalmers Formula Student, Y4 ME (very high ratings)
- MPP126 Product Development Project, Y4 ME (very high ratings)
- PPU195 Product Development Project, Y2 ME BScEng program (low ratings)
- PPU031/032 User Studies - Understanding the User and its Requirements, Y3 IDE BScEng, (transition from poor to high student satisfaction rating)

PPU175 Integrated design and manufacturing, Y2 ME (low student satisfaction rating)

Integrated design and manufacturing is a design-build-test team project course in the second year of the Mechanical Engineering program. The course aim is *to provide possibilities for the students to participate in industry-related product development projects*. Learning outcomes include to be able to: create project definition, analyse customer value creation, design, analyse and evaluate concepts as well as present and argue for the chosen problem solution. The students are divided into teams of five students. The project tasks originate from industry and are focused on the early product development phase, i.e., concept study and test and evaluation of physical prototypes or simulation models, and value-based management. The projects must be realistic, technically challenging and have wide solution spaces. Examples: Development of electric car charging connector (Volvo Cars), and development of automatic detergent dispensers for washing machines (Asko Appliances).

The students are assigned to a team and the project task without the possibilities to have any choices regarding task and teammates. Each team has two Chalmers supervisors and one company representative. The course has integrated teaching and training of project management, communication, and teamwork, and one meeting per week with supervisors. Students follow a pre-defined process consisting of nine steps to deliver the results in a systematic manner. The project results and achievements from each step are assessed and graded with continuous feedback to each team. The individual grade is built as an accumulated moving average, which the students are able to follow. At the end of course, the students' grades take into account the accumulated moving average, the quality of the product, the final report and the presentation as well as the team working process.

The course has been given since 2008 with only minor annual updates. The first course rounds were very well received by the students. The course was new and unique and both students and teaching staff were very enthusiastic and overlooked most issues related to the novelty of the approach including supervision, workload and planning. Recently, students have been less satisfied and the course has not met the high expectations from early course rounds and the marketing of the course. This is manifested in the course questionnaire responses. The mean values of the students' overall impression have been around 2.5, which is well below the approved limit of 3.0. The mean value for all courses in the ME program is 3.8. The students mean that the course idea, aims and projects are good and that they have the required prior knowledge. The students' complaints regard the supervision, planning of the course and above all the experienced workload. The workload is judged to be very high and much higher than in a traditional lecture based course of the same size. The experienced high workload creates stress. Evidently, the students work very hard and the learning is substantial. This is reflected in that all students pass the course and that the mean grade is very high: 4.4 to 4.6 out of 5. This is certainly not the case in a traditional lecture-based course in which normally 30 % of the students fail the first exam, the average grade is around 3.5 and the workload is normally experienced to be reasonable or somewhat high. We have asked students to keep track of their working hours in a diary and put a strict limit on the number of hours that is available in the project. In fact, we do not observe a very high number of actual working hours in PPU175. The explanation is believed to be found in the fact the students have little previous training in dealing with open-ended problems and related uncertainties together with the continual assessment and grading, expectations of high grades and the desire to do well for the external client. These circumstances create negative stress and anxiety, which results in the students perceiving a very high workload. The perceived workload has increased from the previous course rounds despite the teaching staff's attempts to reduce the workload by simplifying the assessment and grading system as well as reducing the number of mandatory lectures. The same contradiction is reported in (Joyce *et al*., 2013).

To summarize, we have identified the following problem factors:

- The variety in project assignments. Not all assignments are suitable for the prescribed project management model.
- The assessment and grading system that drives some students to put too much attention on the grading itself rather than learning to solve the problem.
- Lack of competence or experience of some supervisors.
- The perceived very high workload.

TME131 Project in applied mechanics, Y4 ME, (very high student satisfaction ratings)

Project in applied mechanics is a compulsory course in the master program Applied Mechanics. The course aims *to provide the student with an opportunity to apply knowledge in mathematical modelling using computational and experimental techniques.* The learning outcomes include to be able to: formulate problem definition, master open-ended problems with limited information and uncertainties, use up-to-date simulation tools and experiments as well as to work in teams and identify and handle ethical aspects on development work.

The course has a mixture of students with different technical profiles as well as with backgrounds from different universities worldwide. The students are organized in teams of four to six students. Each team has a unique project originating from the industry or from research at the Department of Mechanics and Maritime Sciences. Most of the research is conducted in cooperation with industry meaning that almost all projects are industry related. Each team has at least one faculty supervisor and often one supervisor from the industry as well. Supervisors formulate projects and submit them to the examiners who approve and make them available to the students. Students then select at least three projects in priority order. The examiners comprise teams based on the students' selections and their grade point averages in the case of exceeded projects. This means that each project has highly motivated students and supervisors with a strong sense of ownership of the projects. In order to resist the bias that this can lead to role of the examiners is disconnected from supervision.

The projects can be design, simulation and/or experimental projects. The projects must be technically challenging, have a wide solution space and include the complete solution chain, i.e., from problem definition to a computational model or experiment. Examples of projects include: design and optimization of vertical axis sea-based wind turbine (Sea Twirl); simulation and testing of weld nut failure at belt pull (Volvo Cars) and CFD simulations and wind tunnel testing of solar-dish unit (Clean Energy).

The course includes integrated lectures and training of methodology, report writing, presentation and ethics. The students' grades are based on both team and individual achievements. Team deliverables include final report and solution, planning report, presentation and opposition that are assessed by the examiners while the individual contributions are assessed by supervisors and by an anonymous peer-assessment within each team based on predefined rubrics. The grades are generally very high with an average above 4.5. The course is very well received by the students with a mean value of the overall impression of 4.3. From the questionnaire and meetings with we students we got clear messages that the students sincerely appreciate to work with technically advanced industrial problems and that they valued the team work highly. The students reported a very high workload in the course but considered it to be worthwhile considering the outcome and, thus, it did not affect the general impression.

The following success factors can be identified:

- A variety of carefully selected projects reflecting different aspects of applied mechanics originating from both industry and research.
- Highly devoted students and supervisors with strong sense of ownership of projects.
- Structured feedback to the students from examiners and room for reflection. A student comment from questionnaire illustrates this: "*I think it was really good with the group feedback meetings at the end of the course and the possibility to really reflect on the group work and what worked well and not as well*."

TME047 Chalmers Formula Student, Y4 ME (very high student ratings)

Chalmers Formula Student is an elective course in the master programs Applied Mechanics, Automotive Engineering, Electric Power Engineering and Systems, Control and Mechatronics. The course runs over the whole academic year. Chalmers Formula Student aims to bridge the gap between engineering education and the industry by training students in a real-life project where they independently design, analyze and develop technology solutions by making data-driven decisions throughout the design, manufacturing and testing of a full-fledged formula racing automobile, and finally put their skills to the test in competitions with various other teams from the rest of the world. Each year, a team of about 30 students designs, builds and tests a new vehicle. A new team is formed every year. Team goals are set to establish aims and expectations. The common goals unify the team and create a sense of purpose to the actions of individuals. Since 2015 the car is electric and thus the course has become multidisciplinary to include mechanical and electrical engineering. It is a highly selective process to be admitted to the course. The students apply for the course and compete for positions in the course by skills, competences and grades. The examiner of the course selects students with different competences to reflect the multidisciplinary nature of the project. The course has one faculty examiner and manager and three faculty supervisors with different technical competences. The students and the teaching staff are highly devoted to the course. The students are assessed based on work performed in the project, written reports, oral presentations and peer reviews. The average grade is very high and the students are very satisfied with the course. The mean value of the students' general impression is uniquely high 4.7. The course requires a much higher workload than the 15 ECTS indicate. The examiner is open with that in the recruitment and the students are fully aware of what is expected from them.

Success factors include:

- Dedicated and competent teaching staff and students.
- A very well-structured work plan with clear milestones.
- An engaging aim in the competitions.

Product Development Project (MPP126) Y4 ME (high student ratings)

Product Development Project (MPP126) is compulsory for the master program in Product Development. It is carried out in collaboration with external partners, typically industrial companies, addressing real development challenges. The aim of the course is thus to make the students experience a real product development project. The project work is carried out in teams with 6-8 students with students from different educational backgrounds, such as mechanical engineering or automation and mechatronics, and from different countries. Each team is given a unique task from a unique external partner. Before assigning students a particular project, many options are presented and the students can vote on five.

The course set-up takes inspiration from CDIO, and covers well the chain C-D-I, starting with planning and requirements setting and ending with a prototype exhibition, while "O" is less well covered. The development tasks are generally open-ended, while the course structure and associated course memo have a relatively high level of detail. Specified learning outcomes cover associated process and method knowledge, but also team dynamics. Assessment and grading is based on the team's project result, along with individual result on written quizzes and team member assessment. For the latter, a specific fill-out form for peer assessment of team member performance has been developed (cf. Gray, 2013). In practice, about 30 % of the students get a grade different from their team project grade.

According to the course questionnaire students are generally satisfied with the course, and the average total score for the four most recent years is 4.03; 4.39; 4.30; 4.38. Looking at the free-text comments, students are consistently happy with the course structure, content, and administration. In addition, students appreciate the variety of projects to select from, as well as having a unique project. So at this education level, students are seemingly mature enough to tackle a project unique for the team, in contrast to the PPU195 case (below). Major complaints in the course refer to problems with the actual team dynamics, but also to team dynamics as a subject although opinions on this differ very much. Another rather common complaint is limited access to the prototype laboratory.

The following success factors can be identified:

- Several alternative projects and industrial partners to select from.
- The course structure has been carefully designed for constructive alignment and CDIO from the beginning and also iteratively improved based on student feedback as well problems noted by the teaching staff.

- Dedicated teaching staff with multi-year experience on the topic as well as the specific course.

Product Development Project (PPU195) for Y2 ME BScEng program (low student satisfaction rating)

Product Development Project (PPU195) is compulsory for the year 2 students of the bachelor program in Mechanical Engineering. The aim of the course is to let the students train systematic methods and tools for product development. The projects are carried out in teams and in collaboration with several industrial partners.

Intended learning outcomes for the students include theoretical concepts and models for product development and project management, as well as the ability to apply them. In addition, as specified, the students are expected to enhance their skills in compiling and presenting the results of a project, orally and in writing. Constructive alignment has been employed in planning the course, but looking deeper on the course structure, one can note a lack of detail in some areas. This applies in particular to criteria for assessment and examination, while there is a predefined four-step (fail, 3, 4, 5) grade scale in place.

The course has scored poorly several years in the course questionnaire, the average total score the four most recent years is 1.76; 2.00; 2.23; 2.48. Indeed, tracking these scores, one can note a somewhat positive trend. This is probably the result of engaging additional competent teachers in the course as well as educating the teachers in design methodology through courses for professionals. However, the student satisfaction with the course is still not acceptable. Interpreting free-text answers in the course questionnaires, possible reasons include varying teacher dedication, varying quality of teaching and supervision, as well as unclear criteria for assessment, grading and feedback. There are also many negative comments about the course literature, in particular when in the form of an app. Course administration as such is satisfactory. On further reflection, possibly the students are at year two of this bachelor's program not fully ready for this kind of project course, including among other things open-ended design tasks in individual teams tackling individual project challenges. In order to address this, the next planned course round will be centered on one large project common for all students in the course.

The following problem factors can be identified:

- Lack of quality assurance in scouting projects, course structure and course delivery.
- The very high perceived workload due to students not enough familiar with open-ended project tasks in combination with unclear communication about expectations.

PPU032 User Studies - Understanding the User and its Requirements for IDE BScEng, (transition from poor to high student satisfaction rating)

User studies - Understanding the user and its requirements (PPU032) is a project-based course with a complementary written exam, compulsory for year 3 students of the bachelor's program in Product Design Engineering. The aim of the course is to get students develop knowledge and skills regarding user requirements elicitation and user-centered design.

Particular learning outcomes after the course include; understanding of the notion user-centered design, ability to apply methods for eliciting user requirements, ability to apply methods for analyzing user data, and ability to effectively communicate user requirements.

From the point of view of course design, this course is an interesting learning object, in particular when it comes to the importance of having an appropriate grade scale in place: The previous version of the course (PPU031) had just a fail/pass grade scale, and it scored poorly in the course questionnaire. The examiner hypothesized that possibly the students suppress the importance of the course, for the benefit of another graded (fail, 3, 4, 5) course taught in parallel. Along with this, the examiner hypothesized that a certain level of student dedication is necessary in order to really enjoy and learn from a course with a project-based set-up. In addition, the examiner collaborates with another examiner giving a similar course with nearly identical content, however with a more detailed grade scale (fail, 3, 4, 5), and that course has always scored well in the course questionnaire. Therefore, an effort to introduce a more detailed grade scale in PPU031 was made, along with formulating the following hypothesis: *"A course without grades (pass/fail) given in parallel with a course with grades (fail, 3, 4, 5) scores poorly in the course questionnaire. This is applicable in particular if the course (pass/fail) has a project- and problem-based pedagogical set-up"*.

When the new grade scale (fail, 3, 4, 5) had been introduced (and the course id became PPU032) and used in practice, the students' satisfaction according to the course questionnaire was significantly improved, and thus the hypothesis was supported. The hypothesis was further supported after another course round with very good student satisfaction. This phenomenon is illustrated in Figure 1 below.

A possible explanation behind the significantly improved student satisfaction includes not only the fact that the detailed grade scale made the students prioritize the course more, but also the fact that a more detailed grade scale calls for assessment criteria to be in place. Thereby, both feedback and justification behind the individual's obtained grade can be improved.

The introduction of the grading scale is identified as the dominating success factor.

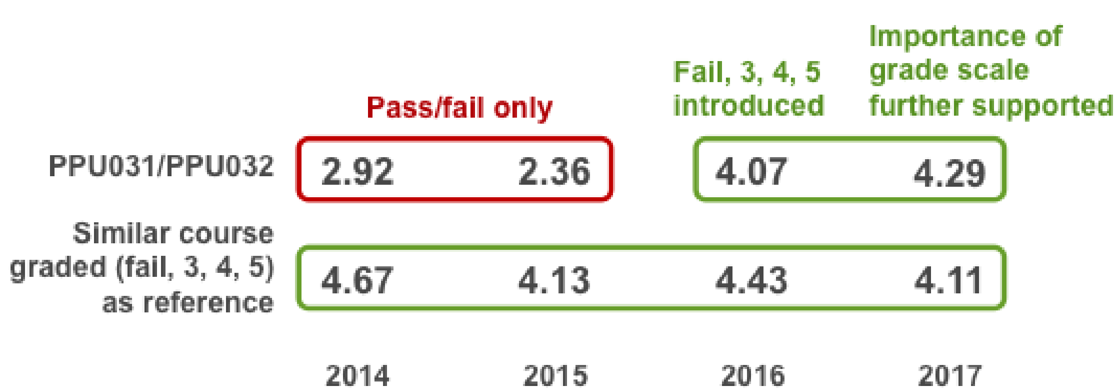

Figure 1. Evolution of students' satisfaction with the course PPU031/PPU032, as a result of introducing a more detailed grade scale, and a comparison with a similar course.

DISCUSSION

The study has found evidence for significant differences in level and variation of student satisfaction in CDIO project courses vs traditional courses for the BSc stage of education. BSc stage CDIO project courses scores are lower and with more variation (see Table 7). In the data from Chalmers, these differences are significant. For MSc level, the tendency is the opposite: MSc level CDIO project courses have higher student satisfaction levels and less variation. However, MSc level differences are not statistically significant. In the following discussion, we analyze a number of aspects that may explain the lower ratings for BSc /higher for MSc.

The study shows that students at BSc level often perceive a too high workload in CDIO project courses (see Table 2). This leads to negative stress and complaints on the course. The students also claimed that the high workload has negative effects on their studies in parallel courses. In free text comments they indicated that the high workload as a main reason for low satisfaction ratings: "*The course is far too demanding, I neglected the parallel courses" or "We have spent an incredible number of hours on the project. Because each submission was graded it was important that they were on top level every week".* Measures such as simplifying assessments and course structure (PPU175 and Joyce, 2013) as well as giving each team a limit on the number of available working hours in the project have been taken without success. In fact student logbooks show that the actual working hours are as expected, and it seems that students overestimate their working hours. Possible explanations include the perceived uncertainties in the problem statement, process and what constitutes a good solution. These factors are probably more influential at BSc level compared to MSc level where students have more experience in coping with uncertainties and ambiguities. Table 2 shows that the workload is not perceived as a problem at MSc level as a high perceived workload does not decrease the overall impression ratings.

In CDIO project courses, it is essential that the technical complexity and level of the project match the students' skills, knowledge and capacity as well as the size of the course. Course leaders need to make sure that projects are appropriate for separate but yet integrated work and sufficiently complex so that the students need to rely on each other's knowledge and skills (Malmqvist *et al*., 2004). For Formula Student and Product development project - courses with high student satisfaction, the projects are either quite structured or the process is more situation-based but at BSc level the projects have an inherent potential conflict in needing to both be based on industry problems and to apply a highly prescribed methodology. Project products and assignments need to be chosen with special care to train the use of the methodology, being authentic and satisfy industry expectations, e.g., methodology may put most attention on concept development while a company may expect more detailed results.

Assessment and grading is a particularly important challenge for CDIO courses. We have observed that it is important to have a grade scale, e.g., fail, 3, 4, 5, rather than just fail or pass. This is to engage the students in the course and to propel quality of project work. In addition, having a more detailed grade scale paves the way for having more appropriate assessment criteria in place (cf. Gray, 2013). However, in a large course with many student teams it may be difficult to provide feedback timely and to provide each team enough time, and the student satisfaction might decrease. On the other hand, in Chalmers cases where the strategy has been promptly implemented the students have been highly satisfied (TME131). In some other Chalmers CDIO project courses, e.g., PPU175, continual assessment and grading is heavily used. The original intent of this was to motivate students to start work early and to enable the examiner to continually secure that the students follow the predefined methodology. However, there is a risk that this set-up dominates daily work too much and creates negative stress and discomfort. To conclude, there has to be an assessment and grading system in place but the level must be balanced regarding content and detailing level.

Above, we have discussed course structure and students' experiences. Important, as well, is the teaching staff and their performance during the course. It is clear that that the professional engineering competence of teachers has been an issue in PPU175 and PPU195. It is also noted as a challenge in the global CDIO survey (Malmqvist *et al*., 2015). To address this issue, staff planning must consider the need for well-prepared and appropriate teachers in the CDIO courses. In addition, there is a need for having plans for competency development in place. Secondly, during delivery, the coordination and communication are crucial both within the teaching team and between teachers and student.

Student satisfaction metrics reflect the impression in direct connection to the course round. Possibly, a different view evolves later in the education or in the work life as the importance and the relevance become more obvious. In addition, a positive experience of early courses affects the students' selection of later courses and specializations. Thus also, CDIO courses at BSc level need to be received sufficiently well among students in order to attract students to the advanced CDIO courses. This is to ensure that the graduates are well prepared for work practice and demands from the industry in line with the cornerstones of the CDIO initiative.

As noted, the study found significant differences in level and variation of student satisfaction between CDIO project courses and regular courses, in particular early in the education. The study only studied one university and the disciplines were mechanical engineering or close to it. It cannot be excluded that a relatively small number of CDIO project courses had a strong influence on the results. Another source of error is that also traditional courses may include CDIO learning experiences to some extent. However, taking this factor into account would likely increase the difference in student satisfaction levels, rather than even out. Further studies at other universities and with additional disciplines would be desirable in order to examine the generalizability of the findings.

CONCLUSIONS

According to student satisfaction data from Chalmers University of Technology, students at BSc level are less satisfied with CDIO courses compared to traditional ones. Still, it is essential to include these courses already on BSc level because students need to gradually develop competences in project management and methodology, team work and communication in order to be prepared for more advanced MSc level CDIO courses.

For CDIO project courses it is particularly important to consider (constructive) alignment between course intended learning outcomes, teaching & learning activities and assessment. Since project-based courses inherently include open-ended problems with a high degree of uncertainty, a relatively high formalization of course structure is needed. Particularly, in CDIO project courses early in the curriculum, it is important to give the students clear timeframes and plan the deadlines for submissions and presentations well. This to avoid that the students work too much and experience stress due to that they want to perform well in industry-sponsored projects. In addition, feedback is crucial but needs to be delivered timely.

Finally, it is crucial with well-prepared, visible and engaged course leaders, and with continual motivation of the relevance of non-technical course content, including ethics, sustainability, and team dynamics.

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BIOGRAPHICAL INFORMATION

Johan Malmqvist is a Professor in Product Development and Dean of Education at Chalmers University of Technology, Gothenburg, Sweden. His current research focuses on information management in the product development process (PLM) and on curriculum development methodology.

Lars Almefelt is Senior Lecturer and researcher at Chalmers University of Technology in Göteborg, Sweden. Previously he was an employee of Volvo Car Corporation, and thus also has many years' experience of industrial development work. Methodology for product innovation is the core of his teaching and research.

Mattias Bingerud is Director of Studies for education programmes in the Maritime field and Education Area Coordinator at Chalmers University of Technology, Gothenburg, Sweden. He is involved in quality evaluation and the development of Chalmers' business intelligence system

Mikael Enelund is a Professor in Structural Dynamics and head of the 5-year MSc program in Mechanical engineering at Chalmers University of Technology. His current research focuses on modeling and optimization of damping and on curriculum developments.

Corresponding author

Professor Johan Malmqvist
Chalmers University of Technology
Department of Industrial & Materials Science
SE-41296 Gothenburg, SWEDEN
+46-31-772 1382
johan.malmqvist@chalmers.se

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CONNECTING NORTH AND SOUTH THROUGH CHALLENGE-DRIVEN EDUCATION

Anders Rosén, Anna-Karin Högfeldt, Ann Lantz, Lena Gumaelius, Ramon Wyss, Margareta Norell Bergendahl, Jesper Vasell

Royal Institute of Technology (KTH)

Suzan K. Lujara

University of Dar Es Salaam (UDSM)

ABSTRACT

This paper contributes with a north-south perspective on the ongoing enhancement of engineering education for sustainable development by giving insights in and results from implementation of challenge driven education (CDE) through joint efforts by the KTH Royal Institute of Technology, the University of Dar es Salaam (UDSM) and other African partner universities. CDE is explained as an evolution of PBL for building learning experiences around societal challenges, engaging external stakeholders, and developing students' abilities to contribute to sustainable development. A case study is presented where students', teachers' and challenge owners' perceptions of a challenge driven approach in engineering education are explored and key drivers and barriers for implementing CDE are clarified.

KEYWORDS

Sustainable development, global challenges, work-based learning, project based learning, internationalization, Standards: 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10

INTRODUCTION

Challenge-Driven Education (CDE), or Challenge-Based Learning (CBL) as it is more or less synonymously denoted, is a relatively new concept that is getting increasing attention. The aim of this paper is to contribute to the further development of this concept by: describing the background, position and role of CDE/CBL in the engineering education evolution; sharing experiences and results from a collaboration between KTH (Royal Institute of Technology) in Sweden and UDSM (University of Dar es Salaam) in Tanzania connecting their educations in a challenge-driven education approach; presenting the KTH Global Development Hub which is a platform for coordinating education, innovation and research activities for global development engineering in collaboration between KTH, UDSM and other African partner universities; and discussing the way forward.

BACKGROUND, POISITION AND ROLE OF CHALLENGE DRIVEN EDUCATION

One of the driving forces in the engineering education reform that has been going on the last couple of decades has been about bridging the gap between engineering education and engineering practice. In the first major reform, occurring during the 1950's, the traditional more practically oriented engineering education had been modernised and rebuilt upon a strong scientific base. However, during the 1980's and 1990's the growing distance between the teaching of engineering science at the universities and the engineering professional skills requested by industry was increasingly criticized and debated (e.g. Gordon 1984, Augustine 1994, Wulf 1998, Crawley 2001). In parallel the concepts of outcomes-based education and constructive alignment were being further concretized promoting a shift from teacher oriented to learner oriented education (e.g. Spady 1988, Biggs 1996, Harden 1999).

In the late 1990's and early 2000's these trends and concepts were gradually being implemented in various education systems, e.g. in EU through the Bologna process, in the US through the reform of the accreditation system of the Accreditation Board for Engineering and Technology (ABET), and similarly in other parts of the world. As an example, the Engineering Criteria 2000 (EC2000) in the reformed ABET accreditation system specified 11 learning outcomes which the accredited education programs should assess and demonstrate that their students achieve. These criteria included mathematical, scientific, and technical knowledge, as well as engineering professional skills, such as solving unstructured problems, communication, and team work (Peterson 1996). The EC2000 were then complemented and significantly expanded in the CDIO Syllabus released in its first version in 2001 forming the cornerstone of the CDIO initiative (Crawley 2001).

Yet another important parallel movement in the second engineering education reformation was the evolution and implementation of problem/project-based learning (PBL). As described by Edström & Kolmos (2013) the principles of PBL and CDIO can be combined and mutually reinforcing when developing learning processes for the development of professional skills, typically in large team based projects resembling authentic engineering practice in CDIO capstone courses.

This second reform of the engineering educations has had tremendous influence, for example on the quality of educations, on the way educations are organized, and on the professional relevance. The world is however changing fast and the engineering skills and roles that were considered relevant at the time this reform was sparked in the 1980's and 1990's will only partly meet the needs for solving the pressing challenges of the 21st century (e.g. Duderstadt 2008, Galloway 2008, Kolmos 2016, Graham 2018). The ABET Engineering Criteria, the CDIO syllabus, as well as various national policies such as the Swedish Higher Education Ordinance, are updated continuously and today they also include aspects of sustainable development (ABET 2009, Crawley 2011, Högskoleförordningen). Whether appropriate adaptation of the engineering educations for the 21st century can be achieved within the paradigm of the second engineering education reform, or if a third reform is needed, however remains to be seen.

Through the formulation of the Sustainable Development Goals (SDG) in the UN 2030 Agenda, a globally shared and agreed view of the grand challenges of our time has been established (UN 2015). High quality education is defined as one sustainable development goal in itself in the 4th SDG where sub-target 4.7 specifically address education for sustainable development. To promote the role of education specific learning outcomes for achieving the SDG:s have been formulated (UN 2017). Various other views on learning outcomes and key competences for education for sustainable development can for example be found in Svanström et al (2008), Duderstadt (2008), de Haan (2010), Wiek et al (2011), Rieckmann (2012), and Eriksson (2006). These typically describe: general engineering competences such as problem solving, systems thinking, handling of complexity, teamwork, and communication; basic literacy for sustainable development such as knowledge of environmental, economic, and social issues related to sustainability and related principles, policies, and goals; highly complex capacities such as consilience, i.e. capacity to integrate knowledge across many disciplines, and capacity to work in multidisciplinary teams characterized by high cultural diversity; and also fundamental human aspects such as integrity, courage and empathy. Engineering for sustainable development will of course also rely on solid traditional scientific basis. Examples of integration of sustainable development in higher education are for example given in Wu & Shen (2016).

Challenge-Driven Education (CDE), or Challenge-Based Learning (CBL) as it synonymously denoted, is learning experiences addressing societal challenges and the broad spectrum of complex learning outcomes related to sustainable development. It is a relatively new concept still in evolution. Some earlier definitions and examples of implementation of CDE/CBL can be found on the primary and secondary levels of education (e.g. Nichols & Cator 2008) as well as in higher education (e.g. Magnell & Högfeldt 2015, Malmqvist et al 2015). In higher education, which is the focus of this paper, CDE/CBL is typically project-based and highly student centred where the learning takes place through the identification, analysis and design of solutions to societal challenges. It closely resembles "real problem based learning" as defined by Kolmos et al (2008), for example in that the project is open ended and that the development of a solution requires knowledge and skills beyond that of a single discipline and therefore involves multi-disciplinary student teams. While PBL could basically address any problem, CDE/CBL specifically address societal challenges in their full complexities, which often has the character of wicked problems as discussed by Malmqvist et al (2015). Further, CDE/CBL aim for solutions that are environmentally, socially and economically sustainable, is generally taking place in international contexts, preferably with high cultural diversity and in close collaboration with external stakeholders who can act as challenge givers and receivers and users of the solutions. With the increasing focus on the grand challenges of our time the concept is getting increasing attention. For example in the KTH Royal Institute of Technology development plan for 2018-2023 it is stated that elements of challenge-driven education should increase in all study programmes (KTH 2018) and a guide has been developed to support teachers in implementing CDE/CBL in their courses (Magnell & Högfeldt 2015).

CASE STUDY OF THE IMPLEMENTATION OF CHALLENGE DRIVEN EDUCATION

In the light of the evolution of engineering education, KTH and UDSM initiated a project to connect their educations in a challenge driven education approach. The vision is to offer the opportunity for students from each country to work on real socio-technical challenges in the other respective country, within their ordinary curriculum. The implementation project *Mutual Innovation Capacity (MIC*) – *Challenge Driven Education for Global Impact* is funded by STINT (The Swedish Foundation for International Cooperation in Research and Higher Education) during a three years' period, until year 2019. Throughout the development work an action based research approach has been applied in order to better understand:

- What are the students', teachers' and challenge owners' perceptions of a challenge driven approach in engineering education?

- What are the key drivers and barriers for the implementation of CDE in a traditional teaching environment?

Findings from the first 1,5 years will be shared, also described in Högfeldt et al (2018). The emphasis will be directed towards the learning experiences among the students, teachers and challenge owners. The technical parts and the actual impact from the students' work will therefore be left aside for now.

UDSM, KTH and Tanesco

UDSM and KTH have strong connections since decades. Through the collaboration between the two institutions, and some joint extra-curricular activities with global challenge competitions, the idea emerged to introduce more formal challenge driven learning experience in the ordinary curriculum. The education at UDSM is to a large extent grounded in traditional teaching approaches, while KTH has long traditions with the CDIO based curriculum, including project and problem based courses. Therefore the plan was made to start by integrating challenge driven education in the curriculum at one of the programs at UDSM. Since the faculty members already had good relations with the electric supply and government owned company Tanesco, a decision was made to continue this collaboration within a CDE setting as well. The challenge that was argued to fit well with the CDE approach for the students was stated as:

Inefficient processes of faults detection, identification and localization of electric supply in Tanzania.

Research Approach and Overview

An action based research approach (Smith, 1996; 2001; 2007) has been applied during the implementation phase of CDE in the curriculum. With this approach, the target is to continuously stay informed of how well things are progressing, and make well-founded decisions for the coming steps. Results from the research are therefore accumulated along a longer time period, and data collected at several occasions. Methods for gathering data can vary based on the type of data and information that is considered needed. Table 1 gives the overview of the action based research approach in the MIC project. The project started in August 2016 with a two days' planning workshop at UDSM, where the project members as well as students and teachers were involved. The result of the planning workshop was a skeleton of the course and an action plan on how to move forward with an invitation to relevant stakeholders from outside the academic context. In October 2016, a challenge definition workshop was carried out together with the invited electrical supply company Tanesco. Three staff members from the company came to the meeting. On the challenge definition day, more specific plans and details were developed for the course to be running smoothly a couple of months. The course was decided to run until the end of July 2017, and run in parallel with other courses, with a total of 9 credits (120 hrs. / semester). In December 2016, the project team met in Stockholm for an evaluation and planning workshop. This was also a time for information gathering, based on the perceived needs to look a bit deeper into learning environments at KTH, supporting challenge driven education approaches.

Table 1. Research Overview

What	When	Where	Who
Planning workshop 1	Aug. 2016	DeS	MIC project team (KTH, UDSM, DIT), students, teachers
Challenge definition workshop	Oct. 2016	DeS	UDSM & TANESCO
Evaluation and planning workshop	Dec. 2016	STHLM	MIC project team (KTH, UDSM, DIT)
Group interview of students	Dec. 2016	Video conf.	KTH members and UDSM students
Evaluation and planning workshop	Feb. 2017	DeS	MIC project team (KTH, UDSM, DIT) students, teachers, Tanesco
Group interview of students	May 2017	Video conf.	KTH members and UDSM students
Evaluation and planning	June 2017	E-mail	MIC project team (KTH, UDSM)
Reflective questionnaire	July-Aug. 2017	online	Teachers, Students, Tanesco staff
Discussing preliminary results	Aug. 2017	STHLM	KTH, UDSM, DIT, and KTH Global development Hub partners
Follow-up and planning workshop	Jan. 2018	DeS	MIC project team (KTH, UDSM), students, teachers, TANESCO

An important outcome of the December 2016 evaluation and planning meeting was the plan for a group interview with students some weeks later. The results from the group interviews (presented below) were presented in an evaluation and planning meeting with project members, teachers, students and Tanesco staff (that had increased from three staff members to 12) in February 2017. The continuing plan for the coming months was designed in the light of the results from the interview. A couple of months later it was decided to plan for a follow-up group interview with the students, to see how well the critical aspects had been met. Via e-mail correspondence the results from the interviews as well as input from teachers and stakeholders, an online questionnaire was designed in order to follow up anonymously how each individual teacher, student and Tanesco staff member perceived the CDE. In July-August 2017, after the CDE course had finished, the questionnaire was open for responders. The results from the questionnaire (presented below) were presented and analyzed in a preliminary result workshop in August 2017, and deeply analyzed at the follow-up and planning workshop in January 2018.

Key Findings From the Student Group Interviews

The expected outcomes, the relations with the stakeholders as well as the workload were the commonly shared critical aspects among the students. In the December interviews students pointed at the lacking clarity concerning what to actually achieve in terms of the project work. They raised the need to have more regular meetings with the Tanesco staff members and preferably also more site visits. Concerning the workload, the students were having six courses in parallel and had only half a day scheduled for the project work with the challenge. The group interview in May 2017 showed clear differences compared with the results in December 2016. The communication between the students and the external stakeholders was perceived to be well established. Workload wise things had improved after the revision of the February follow-up meeting on the results from the December interviews. Students also perceived the picture of the expected outcome to be much clearer, while at the same time lacking instructions on how their work would be assessed and graded by the teachers.

Reflective Questionnaire

8 Tanesco staff members, 4 teachers and 14 students submitted answers to the questionnaire after the CDE course had finished. The questionnaires to the students and the teachers were divided into four sections: the program perspective; the project based approach; the relations with the challenge owners and the course perspective. Each section contained open-ended questions with unlimited space to write the answer. Furthermore, each section contained a question where the respondents were asked to rate how well the specific theme had worked. The questionnaire to the challenge owners included open-ended questions on the relations with the students, the teachers, how the meetings with the students had been organized, and their perceptions on the value of the students' work for Tanesco. There was one question where the Tanesco staff were asked to rate their overall perception of the CDE.

Overall Perceptions Among Students, Teachers and Challenge Owners of CDE

How well the students and the teachers found the CDE to be integrated in their program (curriculum) is shown in Figure 1 and Figure 2. As one can see, the students' perceptions are a bit more scattered than the teachers. At the same time, both groups are positive to the integration of the CDE in the curriculum.

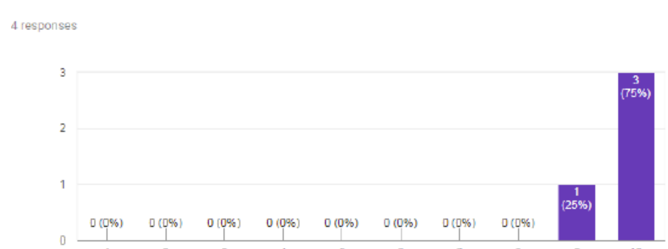

Figure 1. Teachers' rating of the integration of CDE in the curriculum
(1=very bad; 10=very well)

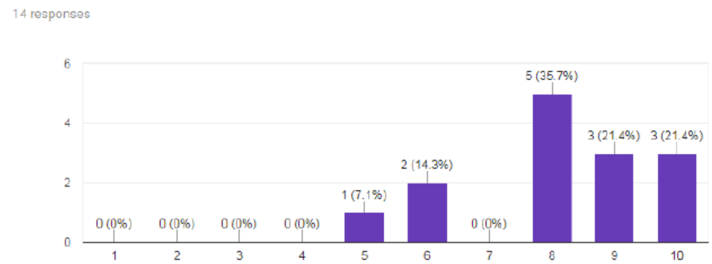

Figure 2. Students' rating of the integration of CDE in the curriculum
(1=very bad; 10=very well)

The perceptions of being a student or a teacher respectively in a project based approach, compared to the traditional teaching they regularly attend, are presented in Figure 3 and Figure 4. The results are clear that the perceptions are positive among all respondents.

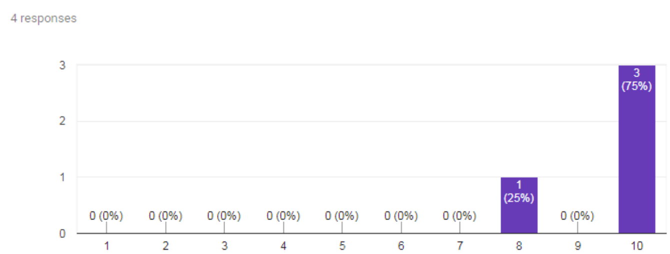

Figure 3. Teachers' rating of working in a project based setting instead of a lecture based setting
(1=very bad; 10=very well)

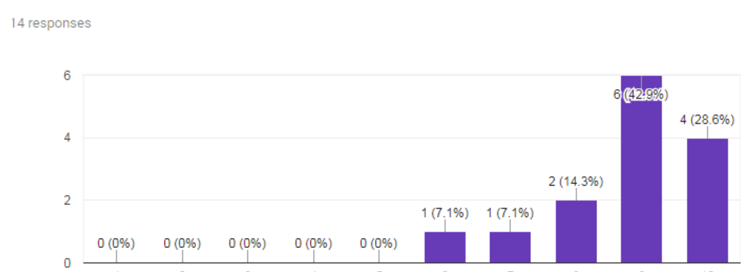

Figure 4. Students' rating of working in a project based setting instead of a lecture based setting
(1=very bad; 10=very well)

Concerning the relations with the challenge owners, in Figure 5 and Figure 6, one of the teachers give a quite low rating (4 of 10) as seen in figure 5. Looking at the reflective answer from this teacher, he/she argues:

“I think, the dialogue and the knowledge and skill transfer between me and the stakeholders have not yet worked out properly. The CDE is new and all key players are taking time to get momentum. There has been uncertainties, which probably could be addressed by establishing more sensitization to stakeholders. The issue here is to make CDE be understood and include CDE into stakeholders programs.”

Another teacher that rates higher (9 of 10) on the relations with the challenge owners writes:

“I think it went very well in that we could invoke their interest and curiosity which was not there initially. They considered the level of students’ knowledge in the area initially to be rather shallow but their opinion changed in the end. At the end of the course they expressed interest to involve the College whenever they will need to evaluate technology related issues.”

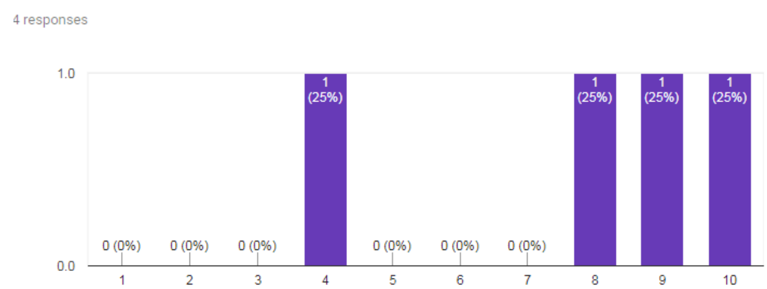

Figure 5. Teachers’ rating of the relations with the challenge owners (1=very bad; 10=very well)

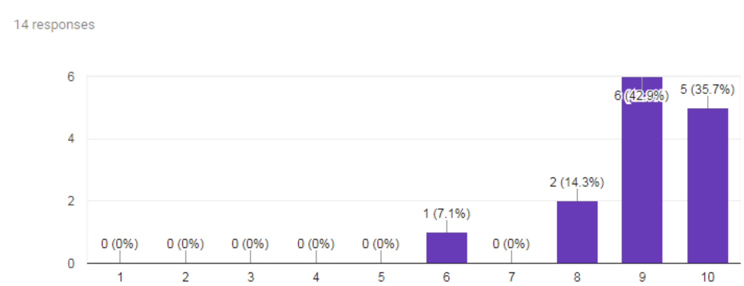

Figure 6. Students’ rating of the relations with the challenge owners (1=very bad; 10=very well)

The Tanesco staff rate the CDE very high, as seen in figure 7.

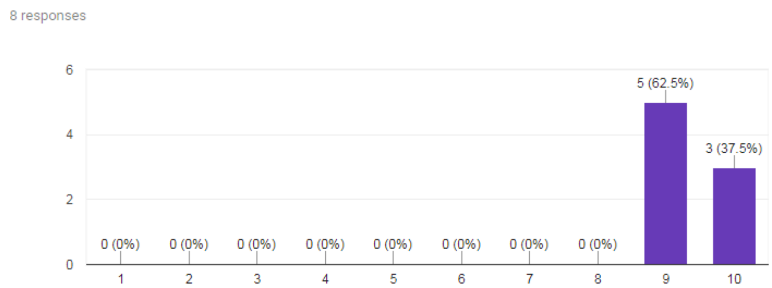

Figure 7. Challenge owners' rating of the overall impression of challenge driven education

Thematic Analysis of the Written Reflections with Activity Theory: Critical Aspects of the Changing Process

With inspiration from Mendonça (2014) who looks at curriculum development in Mozambique, activity theory has been applied in the analysis of the written responses of the open-ended questions in the questionnaire. With activity theory as an analysis tool, one looks at a system of actors, in this case teachers and students. The focus is how the actors act and interplay in the rules of the system they are in, in this case the educational system. The strength with activity theory is to apply the analysis when the system is changed, when the target or objective changes, or when new objects or actors enter the system, as in this case when shifting from a traditional to a challenge driven approach. By this, one can search for critical aspects, both obstacles and drivers, of the changing process, in order to improve curriculum reform and changing processes. With activity theory one is not searching for one single right answer, but rather to explain and give thematic descriptions of something that is under continuous development. The categories are briefly explained with a few quotes from students (S1-S14), teachers (T1-T4) and challenge owners (C1-C8), and more thoroughly explained in Högfeldt et al (2018).

New Intrinsic Motivation due to Reality, Holism and System Perspective

A key driver for the high motivation among students and teachers is to be working with real life problems which are relevant and pressing. S8 writes that "the project is a real life challenge in Tanzania and many developing countries and I feel happy and grateful to get an opportunity to work with this project in an academic context". T4 argues that academia and society otherwise have limited connections, and the syllabus remains quite unchanged "while globalization effects are felt daily". C2 argues that the motivation to collaborate lies in the free dialogue and a "partnership and shared understanding of the motive behind the methodologies for the program. This has also been the key to success in meeting deadlines and having a working solution". The students are often referring to insights of the holistic and system level aspects. S7 was motivated by being faced with "how to understand the problem from their perspective, obtain site requirements and professional negotiation". S7 continues and writes that this "has introduced me to the idea that, when solving a particular problem, I have to consider how it will integrate and co-exist with available or upcoming solutions. (…). At the beginning we had our opinions of the problems facing the energy industry, particularly the main electrical company. But when we met them, they had most of our listed problems solved under various stages of implementation. The lesson learnt was that, we should have started on their side".

New Intersections of Students', Teachers' and Industry Partners' Arenas

The rules and activities are clearly flipped in new forms with the CDE compared with the traditional teaching environment as well as with the traditional relations with the electric supply company, which all three actors reflect upon in their texts. S5 argues that teachers are no longer "feeder of materials" which he/she finds positive for the creativity. Instead of being in the hands of the teachers' planning, S10 has started to think and act more and S8 states that "the nature of the project was more driven by students' ideas rather than teachers' wishes". S1 and S6 explain that they feel they are closer to the teacher in this new setting, and that the teachers are more friendly. T1 writes that the CDE format "improves my role as a supervisor because the students have from the beginning known that they own the challenge". The role for the teacher is, according to T2 to "democratically allowing students to identify their challenges, formulate method and solutions". While very little curiosity and interest was shown initially by the challenge owners, according to T3, and that they were even "reluctant" in the beginning, as stated by S14, and according to S8 "not aware about the approach", as the CDE progressed "you can tell the huge difference", according to S6, when "stakeholders were very cooperative and their input was very significant". The challenge owners' ideas gave students and supervisors a feeling of "holistic knowledge", writes S9. The stakeholders' "appreciations, comments and recommendation built a working hard spirit and feeling of not letting down the university, supervisors and our self as well", according to S1. S7 argues that the challenge owners "bridge the gap between industry and academy". For Tanesco there is often very little "time for research study", writes C1 who appreciates the students' contributions to more thorough improvement suggestions. T3 explains that "at the end of the course they [the challenge owners] expressed interest to involve the College whenever they will need to evaluate technology related issues".

The Interplay between Independence and Dependence among the Students

When talking about project based learning, the discussion concerning independence is quite common. What has been found as crucial for the students in this context has been the dependence of each other. And the interplay of the independence and dependence has been interesting to look at. This interplay could be summarized by S8 who writes: "I managed to learn how to accomplish the assigned tasks so as to contribute to the group challenge as a whole, because most of our individual tasks depend on one another". S13 explains that "the course forced me to make sure I work hard on my part to make entire system to work (...) to accomplish a common goal". This social pressure is even more emphasized by S1 who writes: "if other fails to deliver means the whole group has failed". Also the teachers find this new interplay to be of importance in the CDE setting. T4 states that "each group must know the knowledge, skills and experiences of every group member". "They find that they have to cooperate as a team in order to effectively tackle the challenge that they face", argues T1.

New Arenas and Voices for Feedback

As will often happen in a project based setting, students as well as teachers will engage in new forms of discussions on learning, achievements and performance. This is also true for the implementation of CDE at the UDSM. Here the feedback will also happen in new places and among actors that are not in the academic context, such as the Tanesco staff and different types of users of the electric supply. The continuously increased dialogue between the stakeholders has according to T1 "managed to re-align the students to the real challenge each time there is a meeting so that the students do not come up with unrealistic, unimplementable [sic] solutions". S1 thinks that having both input from teachers and Tanesco has been "the perfect knowledge combo". In the CDE setting, working on challenges that are on this complexity level, forces the teachers to be actively involved in the feedback from Tanesco in order to understand and grasp how to best supervise the students. T1 writes: "The stakeholders' inputs help to guide the supervision work so that the students work on what is achievable". Furthermore, the challenge owners as well, receive feedback that is of crucial value.

Transformational Aspects of the Curriculum and Organization

It has been obvious that CDE cannot be implemented for real without affecting the surrounding curriculum and organization. The first clear sign on this was the heavy workload that the students experienced, with having as much as six parallel courses in the early phases of the project work in CDE. The workload was improved by for instance restructuring a parallel reading course, so that the students searched for readings related to the challenge. T1 argues that "it was sometimes not so straightforward to fit the other courses to the challenge. In due course however, it will be possible to conduct the other courses with basis on the challenges in hand". The previous knowledge and experience among the students come up as important aspects in the project work, where students point out the importance of heterogeneity in order to embrace a challenge like electric supply and faults detection. This opens up ideas for how to organize the CDE in the future to bring in more knowledge. At the same time, this can be challenging. "The course takes diversity in backgrounds, from computer science and engineering to electronics and electrical engineering, in our class for example. Three students were with pure computer science and three had engineering backgrounds, those with computer science background had a bit of challenge especially when we were doing the microprocessor and embedded systems which required electrical know how and electronics backgrounds". Various ways of organizing spaces, meetings with stakeholders, laboratories and maker spaces are also important to continuously develop and find resource efficient forms for. S4 writes that "the workshops and visits to stakeholders' premises have been helpful in learning and gaining knowledge and skills related to the project".

Conclusions of the First Phase of CDE Implementation at UDSM

The interviews, observations and questionnaires reveal a successful implementation of challenge driven education at the College of ICT at University of Dar es Salaam. There have been continuous hinders, that have been possible to reduce such as heavy workload, low understanding of expected outcome and too little dialogue between stakeholders. The overall ratings of the CDE experience are very high from all three actors' side. The key aspects that have been revealed in the change process from traditional to challenge driven education have been organized in five thematic areas: New intrinsic motivation; new intersections; new voices and arenas; new interplay of independence and dependence and transformational aspects of organization and curriculum.

KTH GLOBAL DEVELOPMENT HUB

In 2017 KTH established the Global Development Hub (GDH) as a platform for coordinating education, innovation and research activities for global development engineering (Bergendahl et al 2018). The MIC/STINT project described in the previous section can be seen as a pilot. In addition to UDSM partnerships have also been established between KTH and Strathmore University in Kenya, Botho University in Botswana, University of Rwanda, and Addis Ababa Institute of Technology. GDH also has a close partnership with Openlab in Stockholm which for example contributes with expertise in design thinking and challenge-driven innovation.

The aim of GDH is to promote development of mutual innovation capacity and sustainable solutions to local societal challenges with relevance for Sweden as well as for the African partner countries. This will be achieved by bringing together students, faculty, societal stakeholders and innovation systems through new ways of collaborating cross-culturally and cross-disciplinary towards the UN Sustainable Development Goals (SDG). The primary objective of GDH is to:

- promote, facilitate and co-fund implementation of a challenge-driven education (CDE) concept into the regular curricula of the educational programs at KTH and partner universities;
- facilitate and co-fund student exchange between KTH and the partner universities;
- support teachers training and facilitate collegial collaboration between teachers within KTH and between KTH and the partner universities;
- facilitate collaboration between the universities and external stakeholders.
- coordinate research to promote further development, enhance quality and provide evidence.

As illustrated in Figure 8 the GDH CDE concept can be described as two parallel and closely interrelated processes – a learning process and an innovation process. The starting point are challenges in the local societal context of the respective universities, which are related to one or several of the SDG:s. The challenges are typically defined in dialogue between the universities, students and engaged external stakeholders who can act as challenge owners and receivers and users of the results (e.g. municipalities, private sector corporations, or NGOs). The target for the learning process is innovation capacity, primarily in terms of the students' developed knowledge, skills, professional confidence, and network, but also competences and network built up within involved stakeholders organizations and universities through the collaboration. The target for the innovation process is to have sustainable solutions to the addressed challenges. As illustrated in Figure 8 the core element are challenge-driven courses established at KTH and the partner universities. Multi-perspective student teams are achieved, either by students from the partner universities joining KTH teams in KTH courses during one exchange semester at KTH, or vice versa by KTH students going on exchange joining teams and courses at the partner universities. The outcome of the courses will, in addition to the learning, typically be proposals of solutions to the addressed challenges. Proposals with high potential will then be taken further in post-course innovation processes for actual implementation in the society, either by the involved stakeholders, by other actors in the local innovation systems, or by successive student projects.

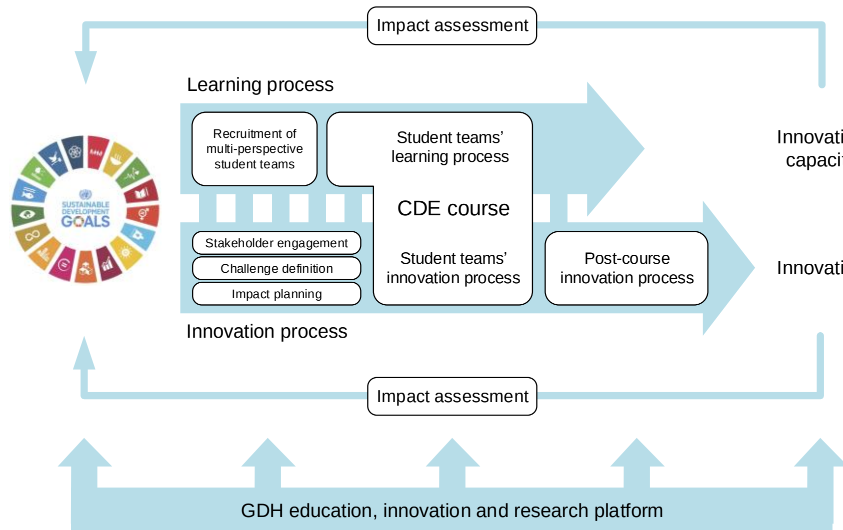

Figure 8. The GDH CDE concept.

The first four students from Strathmore and one from UDSM were on exchange at KTH during the autumn semester 2017 joining the challenge-driven course provided by OpenLab. The first seven KTH students were on exchange at Strathmore during the spring 2018 joining a newly developed CDE course. Another ten students from the partner universities are planned to come to KTH during the autumn 2018. Then, as more challenge driven courses are being established at KTH and at the partner universities, increasing numbers of students can be involved. The concept is scalable and more partner universities might be added in the future.

CONCLUDING REMARKS

This paper has contributed with a north-south perspective on the ongoing enhancement of engineering education for sustainable development by giving insights in and results from the implementation of challenge driven education (CDE) through joint efforts by the KTH Royal Institute of Technology, the University of Dar es Salaam (UDSM) and other African partner universities. CDE has been explained as an evolution of PBL for building learning experiences around societal challenges, engaging external stakeholders, and developing students' abilities to contribute to sustainable development. An action based case study has been presented where students', teachers' and challenge owners' perceptions of a challenge driven approach in engineering education have been explored and key drivers and barriers for implementing CDE have been clarified. It has been proven that the integration of CDE in the curriculum is highly appreciated by students, teachers and challenge owners. While integrating a CDE approach in a traditional educational system, the obstacles and barriers discovered in the UDSM case may contribute with fruitful ideas.

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BIOGRAPHICAL INFORMATION

Anders Rosén is associate professor in naval architecture at the KTH Royal Institute of Technology sharing his time between the KTH Centre for Naval Architecture, the KTH Higher Education Research and Development unit, and the KTH Global Development Hub. Teaching ship design and educational development leadership. Current main focus on integration of sustainable development and global competences in engineering educations e.g. through workshops with students and faculty and development of the challenge driven education concept. Deputy Director of the KTH Global Development Hub.

Anna-Karin Högfeldt is a Lecturer, PhD student and Director of Faculty Training at the Royal Institute of Technology. Anna-Karin is actively involved in Nordic and International/cross-continental education evaluation, development and research projects. She is one of the main authors of the book Guide to Challenge Driven Education (2015), which originates from a collaboration project with partners in East Africa. At KTH, she has worked twelve years strategically to support management, schools, education program directors and individual teachers to strengthen education and system level approaches.

Jesper Vasell, PhD, is Director of Global Development Hub at KTH Royal Institute of Technology. He is an experienced entrepreneur and innovation system developer with over 20 years of experience from many different roles in innovation support and development, both within and outside academia. Extensive experience of innovation system development and capacity building for innovation in developing countries, primarily in eastern and southern Africa. Co-founder of several start-up companies in Sweden and USA, as well as two commercial business incubators. He holds a PhD in Computer Science and a Master's degree in Electrical Engineering, both from Chalmers University of Technology.

Ramon Wyss is a professor in theoretical nuclear physics at the KTH Royal Institute of Technology, also serves as an honorary guest professor at Peking University. Served as vice president of KTH in charge of international education at KTH from 2002-2016 and has been engaged in the leadership of different European university networks contributing decisively to the internationalization of Swedish engineering education. Jointly with Prof Margareta Norell Bergendahl, KTH Global development was initiated 2016, building mutual innovation capacity with partner institutions in sub Saharan Africa.

Ann Lantz is professor in Human-Computer Interaction at Royal Institute of Technology, KTH. Lantz is from 1st of January 2018 acting as deputy head and director of first and second cycle education at the school Electrical Engineering and Computer Science. Lantz' latest research is on communication and cognitive disabilities, and, challenge driven education using design thinking as a method focusing on the challenge owners. The latest publication of Lantz is a book on Digitalization and work.

Margareta Norell Bergendahl is professor in Integrated Product Development (IPD) at KTH, the Royal Institute of Technology in Sweden. The work in IPD covers work procedures, tools and organizing for efficient and innovative industrial product development. She has held positions as Vice President and Pro-rector of KTH for many years, the last with responsibility to develop strategic relations with industry and society. During the years she has initiated a number of cross-disciplinary collaboration programs. The last years she has, together with professor Ramon Wyss, been responsible for the initiation of KTH Global Development Hub.

Lena Gumaelius has a position as associate professor at the Department of Learning, KTH. The last few years her research focus is in engineering education, where she studies the development of engineering education at all levels in school and she has a special interest for studying the effect of outreach and attractiveness of technology. Lena has a background as a researcher in Biotechnology. Lena has been head of the Department of Learning for many years and was until 2018 the Dean of the ECE-school (Education and Communication in Engineering sciences) at KTH. She is now the head of the board of the KTH Global Development Hub.

Suzan K. Lujara received B.Eng.Degree in Electrical and Electronics Engineering from the University of Mysore India in 1990 and Master of Science (Electronics and Information Technology) from the University of Dar es Salaam in 2001. In 2011, she received her PhD Degree in Computer Engineering and Information Technology from the University of Dar es Salaam – Tanzania. Currently, she the the Principal Laboratory Engineer in the Department of Computer Science and Engineering, College of Information and Communication Technologies (CoICT), University of Dar es Salaam.

Corresponding author

Anna-Karin Högfeldt
KTH Royal Institute of Technology
SE10044 Stockholm, Sweden
+46(0)7727259
akhog@kth.se