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CDIO Initiative
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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 135 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 13th International CDIO Conference takes place in Calgary, Canada, June 18–22, 2017, hosted by the Schulich School of Engineering at the University of Calgary. The organizers together with the City of Calgary welcome you to the event!

The main theme of this year is *Engineering Education in the Digital Age*. 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 two types of contributions, Full Papers and Projects in Progress. The Full Papers fall into three tracks: Advances in CDIO, CDIO Implementation, and Engineering Education Research. All Full Papers have undergone a full single-blind review process to meet scholarly standards. The CDIO Projects in Progress contributions describe current activities and initial developments, and were selected by the program committee co-chairs based on the submitted abstracts.

Originally, 170 abstracts were submitted to the conference. The authors of the accepted Full Paper abstracts submitted 108 Full Paper manuscripts to the peer review process. During the review, 310 review reports were filed by 91 members of the 2017 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 full 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 102 accepted full papers that will be presented at the conference, of which 5 are Advances in CDIO; 48 CDIO Implementation; and 11
Engineering Education Research. These papers have been written by 173 different authors representing 30 countries. This book is available as an electronic publication only. In addition to the Full Papers, 32 CDIO Project in Progress contributions will be presented at the conference and are not included in this publication.

We hope that you find these contributions valuable in developing 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. A total of 80 universities from 35 countries, representing six continents, will be present during 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 2017 experience!

Calgary, June 15, 2017

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ADVANCES IN CDIO
A PROPOSAL FOR INTRODUCING OPTIONAL CDIO STANDARDS

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ABSTRACT

The first version of the CDIO standards was presented in 2005 (Brodeur & Crawley, 2005). The aim of this paper is to explore if meeting current CDIO standards still corresponds to the expectations placed on graduates from leading engineering programs worldwide. In the paper, we first identify engineering competencies that are claimed to be essential both today and in the future, focusing on competencies whose relative importance have grown since the early 2000’s. We also identify pedagogical practices that aim to develop these particular competences. We then propose that these emerging skills and best practices should be incorporated in CDIO as “optional” CDIO standards. Whereas the original or “basic” CDIO standards are scoped with the expectations of a bachelor program in mind, an “optional” CDIO standard indicates a more advanced or broadened competence. A set of potential optional CDIO standards is enumerated. Seven of the potential optional CDIO standards are then elaborated in the same format as the current standards, i.e., with a description, rationale and suggested evidence.

KEYWORDS

CDIO Standards, Standards 1-12

INTRODUCTION

The CDIO standards are a key part of the CDIO framework by defining the distinguishing features of a CDIO program, by serving as guidelines for educational reform, and by providing a tool for continuous improvement (Crawley et al., 2014).
The CDIO standards were initially presented in 2005 (Brodeur & Crawley, 2005) and described more fully by Crawley et al. (2007). Rubrics for evaluating programs according to the standards were introduced in 2010. The CDIO standards have since been updated to version 2.0 (Crawley et al., 2014) and the rubrics have been further modified (Bennedsen et al., 2016). These modifications have been relatively minor and have not changed the scope or the main contents of the standards.

While the CDIO standards have been stable during this time period the external context of engineering education has evolved. It is generally recognized that there is increasing need for engineering graduates with competencies in sustainable development, innovation and entrepreneurship, internationalization, multidisciplinary and sociotechnical problem-solving, and digitalization, to mention only a few emerging needed skills. Moreover, recent pedagogical development work conducted within the engineering community was not considered in the original CDIO standards. Further, the CDIO standards are based on the premise of a single-cycle engineering bachelor degree, not a two-cycle bachelor+master degree. There is need to revisit the CDIO standards to evaluate if they are still valid as a benchmark for an internationally leading engineering program.

In this paper, we

- Review the recent literature on needed capabilities of future engineers and on emerging pedagogical approaches that develop these capabilities;
- Propose a structure that supports a controlled expansion of the CDIO standards, in consideration of the pedagogical developments within and beyond the CDIO community;
- Propose a set of requirements for an optional CDIO standard, including that a new standard should reflect the main characteristics of a CDIO program, that it should be generally applicable, i.e. not discipline specific and that it should be evident in a substantial number of CDIO programs as a distinguishing feature;
- Identify and elaborate a set of potential additional, “optional” CDIO standards.

The ultimate aim of the paper is to propose a draft version of the CDIO standards version 3 that can serve as the basis for future discussion, refinement and possibly adoption by the CDIO community. We wish to strongly emphasize that the paper is intended as a starting point for the discussion, not as the final decision on whether the concept of optional standards should be introduced. We also wish to emphasize that the proposed list of optional standards presented in the paper is not final in any way.

LITERATURE REVIEW

Let us start by reviewing some statements on the challenges that future engineers will need to address and the associated implications for the knowledge and skills of graduating engineers, focusing on aspects that are not addressed by the original CDIO standards.

The US National Academy of Engineering (2008) identified 14 “grand challenges” that engineers need to address during the 21st century. The challenges can be grouped into “Sustaining life on earth”, “Living secure from threats”, “Promoting healthy living”, and “Living and learning with joy”. Al-Atabi (2013) argues that a program that prepares students to address the grand challenges needs to include research experience, to have an integrated curriculum, to train entrepreneurship, to provide a global dimension and to offer service learning.
Crawley et al. (2011) provided a summarized critique on the development ideas for the first version of the CDIO syllabus. The critique argued for a more visible position for knowledge and skills related to innovation, invention, sustainability, international factors, dialoguing, leadership and entrepreneurship. As a consequence, a number of changes were made to the CDIO syllabus, including new sections entitled “Leading engineering endeavors” and “Engineering entrepreneurship”. However, no additions were made to the CDIO standards.

Kamp (2014) argued that current engineering programs typically put too much emphasis on technical knowledge and processes in their curricula, while neglecting the socio-economical context in which technical solutions are only part of the solution. Kamp further identified a set of key capabilities for future engineers including creative thinking, decision-making, leadership, global mindset and interdisciplinary thinking. However, the most important capability of future engineers, Kamp concluded, is a positive approach towards life-long learning.

In the CDIO implementation survey (Malmqvist et al., 2015), respondents were also asked to point out future directions for the CDIO framework. Requests were raised for formulating a vision for engineer’s work in 2030 and elaborating on the consequences for learning outcomes for engineering education, for standards suitable for assessing master programs, and for inclusion of novel pedagogical ideas and concepts, such as on-line education, to the CDIO framework.

Many authors have published ideas and approaches on how to develop these emerging skillsets. Fai (2011) and Taajamaa et al. (2011) have suggested to add “design thinking” methods (Rowe, 1991) to the front end of the CDIO process, thereby exposing and providing students with tools for dealing with complex, multidisciplinary problems where problem identification itself is challenging. Campbell and Beck (2010) proposed a CDIO standard for internationalization and mobility. Enelund et al. (2011) reported on a concept for a computational mathematics curriculum, enabling more authentic, simulation-driven mathematics training for engineering students. Enelund et al. (2013) presented an approach to consider sustainability aspects throughout an engineering program.

These proposals have so far not been developed as and codified into CDIO standards. (Campbell and Beck’s Internationalization and mobility standard was suggested as a CDIO standard in 2010, but not accepted at the time.) However, the examples listed above a fertile starting point for formulating additional CDIO standards, as is the aim of this paper.

DEFINITION AND IDENTIFICATION OF POTENTIAL OPTIONAL STANDARDS

In this section, we explain the concept of an optional CDIO standard and outline the requirements on such a standard to be accepted. Based on the findings in the literature review, we list a number of potential optional CDIO standards, which are then screened against the list of requirements.

We consider that the adaptation of an optional CDIO standard assumes that the original twelve, “basic” CDIO standards provide the fundamentals for a program. The basic CDIO standards form a core to which optional CDIO standards can be added to indicate a particular profile or development direction for a program, but the optional standards do not replace any of the basic standards. See Figure 1 for an illustration.
The requirements on an optional CDIO standard start from the purpose of the basic CDIO standards, i.e., to express the context and goals, the curriculum, the learning environment, the teaching, learning and assessment approaches, the faculty development support, and the quality assurance system for the program. A CDIO standard is to be used for:

- Program design
- Periodic program self-evaluation
- Benchmarking, discussions and co-development with other programs

The twelve basic CDIO standards are “best practices” scoped with the expectations on current engineering programs leading to a bachelor degree. We argue that in order to qualify as an optional CDIO standard, a pedagogical best practice should:

- Address an important, typically emerging, need in engineering education
- Be based on an novel, yet well codified, pedagogical approach, developed within or outside of the CDIO community
- Be widely applicable, i.e. not be specific to a single discipline (for example, civil engineering)
- Not be sufficiently addressed by interpretation of a current standard (such as integrated learning)
- Reflect a program-level approach, and not be obtainable by implementation in a single course
- Be evident in a substantial number of CDIO programs as a distinguishing feature
- Support the definition of a distinct program profile, beyond basic CDIO
- Be assessable by the CDIO standards rubrics
In the literature review, we identified the following potential optional CDIO standards, listed in alphabetical order:

- Digital learning (Kamp, 2014; Malmqvist et al., 2015)
- Diversity (Crawley et al., 2011)
- Engineering entrepreneurship (Crawley et al., 2011; Mäkimurto-Koivumaa & Belt, 2015)
- Engineering ethics (van de Poel & Royakkers, 2011)
- Internationalization & mobility (Campbell & Beck, 2010)
- Leadership (Crawley et al., 2011)
- Master-level CDIO programs (Malmqvist et al., 2015)
- Multidisciplinary, collaborative skills (Kamp, 2014)
- Research-integrated education (Al-Atabi, 2013; Kamp, 2014)
- Simulation-based mathematics (Enelund et al., 2011)
- Sustainable development (National Academy of Engineering, 2008, Enelund et al., 2013)
- Workplace and community integration (National Academy of Engineering, 2008)

**ELABORATION OF PROPOSED OPTIONAL CDIO STANDARDS**

This section further elaborates some proposed optional CDIO standards. The format is the same as for the original standards, i.e., a standard is given a characterization, a description, a motivating rationale and a list of examples of evidence that may be used to document that the standard is being addressed.

Seven standards were chosen for elaboration in this paper, i.e., Digital learning, Engineering entrepreneurship, Internationalization & mobility, Simulation-based mathematics, Research-integrated education, Workplace and community integration, and Sustainable development, as shown in Figures 2-8. The primary criterion for selection was the availability of examples of best practice for the optional standard. The remaining potential optional CDIO standards are left for future development.
**Digital learning standard**  
*(Brockhoff, 2011; Hugo, 2014; Cheah et al., 2016; Cronhjort & Weurlander, 2016)*

Engineering programs that support and enhance the quality of student learning, and teaching, through digital learning tools and environments.

**Description**

A program that employs digital learning technology to enhance the student learning experience as well as teaching effectiveness. Course development and delivery are assisted using appropriate e-learning development infrastructure. Program and course development is assisted by staff familiar with the CDIO framework for engineering education development, as well as expertise in instructional design, multimedia content development (recording, editing, and distribution), and assessment.

**Rationale**

The ability to augment learning activities through digital tools and resources provides instructors, program designers, and students with increased flexibility. The physical design of the teaching space and the duration of the contact time enable instructors to develop more interactive teaching and learning activities. Digital content repositories from prerequisite courses enable the efficient reactivation of knowledge, facilitating scaffolding across the curriculum. Program designers can structure student learning in a manner that provides increased learning flexibility including student mobility.

**Evidence**

- Courses within a program that use digital learning methods for either partial or full lecture content delivery
- Learning environments that support blended or flipped course delivery, enabling instructor-student contact time to be used for higher-level learning activities including project-based learning, inquiry-based learning, and active learning,
- Digital support of novel curriculum structures including coursework on internship or during non-residential study semesters
- Infrastructure and resources that support the design, development, and distribution of digital content

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Figure 2. Digital learning standard
**Engineering entrepreneurship standard**  
(*based on section 4.8 in CDIO syllabus 2.0 (Crawley et al., 2011) and inspired by Mäkimurto-Koivumaa & Belt, 2015*)

Engineering programs that actively develop their graduate’s abilities to, in addition to conceive, design, implement and operate complex products, systems and processes, to commercialize technology and to create business ventures based on new technology.

**Description**

A curriculum that is permeated with entrepreneurial learning experiences. Entrepreneurial competence is developed *through* entrepreneurship learning activities (e.g. by students performing value creation projects in the community), by learning about entrepreneurship (e.g., marketing, intellectual property rights), by learning *in* entrepreneurial settings (e.g., student incubators or student-run companies) and *learning for* entrepreneurship (e.g. business model creation tools). The entrepreneurial learning is supported by adapted learning environment and by staff with entrepreneurial competence.

**Rationale**

The role of engineers has broadened from designing and implementing technical solutions to forming business ventures based on technological innovations. Startups are increasingly based on ideas developed by students during their studies, or on ideas and intellectual property owned by university researchers that students further develop and commercialize. The needed competences include opportunity identification, business planning, intellectual property rights, company financing and marketing.

**Evidence**

- Program goal documents that identify entrepreneur as a potential professional role for the program’s graduates
- Specific and detailed program learning outcomes related to engineering entrepreneurship knowledge, skills and attributes, including, for example, business plan development, company capitalization and marketing
- Learning activities about, for, in and through entrepreneurship are visible in multiple places in the curriculum
- Learning environments that support education for entrepreneurship, such as student business incubators
- Data on students or recent graduates who start companies based on technical ideas that they have developed themselves or acquired from university researchers

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*Figure 3. Engineering entrepreneurship standard*
**Internationalization & mobility standard (proposed by Campbell & Beck (2010))**

Programs and organizational commitment which exposes students to foreign cultures, and promotes and enables transportability of curriculum, portability of qualifications, joint awards, transparent recognition and international mobility.

**Description:** CDIO Program Internationalization and Mobility encourages and recognizes organizational commitment, which prepares engineers for a global environment and to expose them to a rich set of international experiences and contexts during their studies. It represents the exposure, promotion, facilitation, opportunity and scholarship of an internationalized curriculum, qualifications and international mobility of students.

**Rationale:** Graduate engineers of the future will increasingly need to be international in their outlook and experience, and be prepared to operate globally. Businesses have to compete and collaborate on a global scale, and operate across national and international borders with organizational environments being increasingly complex, dynamic and with more interdependencies. Our challenge as educational institutions is to aid our students to prepare for this global environment.

**Evidence** may include, non-exclusively, one or more of the following:
- The embedding of authentic cultural awareness and experiences within the curriculum, or social activities
- Opportunities made available for students to learn second languages
- Programs which encourage and recognize study abroad, and other international experiences (including internships, exchanges) for credit
- Establishment of a mobility window within programs and curriculum
- An ePortfolio facility, which links student learning outcomes with artifacts, and graduate attributes and competencies, which are recognized through international accords.
- A demonstrable and tangible institutional commitment to internationalization and student mobility
- Complementary partnerships between international universities
- Transparent expectations of student learning outcomes from an international experience
- International benchmarking of programs
- Active involvement in international engineering education scholarly activities
- Program accreditation with international cross-accreditation
- Transparency in institutional cross-credit for study abroad

Figure 4. Internationalization and mobility standards
Simulation-based mathematics standard  
(Enelund et al., 2011)

Engineering programs for which the mathematics curriculum is infused with programming, numerical modeling and simulation from the start.

Description
Basic mathematics courses mix the learning of mathematical lemmas and methods with direct practice of numerical program solving, aided by mathematical software. Mathematics courses teach programming of algorithms for equation solving.

Rationale
The mathematics courses will include more authentic and complex problems. Realistic decision-making situations can be simulated. The connection to science and engineering courses can be reinforced. A better understanding of what advanced mathematics can be used for and how that it carried out strengthens student motivation.

Evidence
- Specific and detailed program learning outcomes address mathematical programming, modeling and simulation
- Specific and detailed course learning outcomes address mathematical programming, modeling and simulation
- The programme idea brings forward advanced simulation skills as distinctive skill of its graduates
- Use of mathematical software in basic mathematical courses
- Common, mutually-supporting, simulation-based assignments in mathematics and engineering science courses

Figure 5. Simulation-based mathematics standard
Research-integrated education standard
(Gierke et al., 1998; King et al., 1999; Jenkins & Healey, 2005; Magnell, Söderlind & Geschwind, 2014)

Engineering programs that include one or more research experiences as part of student learning.

Description
A program that includes contact with research, such as research-tutored, research-based or research-oriented learning experiences (Healey, 2005). In hands-on open-ended experimental activities, students are provided with access to a laboratory with appropriate equipment to investigate problems, processes or phenomena.

Rationale
Through open-ended knowledge discovery experiences, students can form pro-active habits for learning, and for critical and creative thinking, i.e. the life-long learning skills necessary in a changing world. Students need to be exposed to active researchers as role-models, to approaches and methods for building new knowledge, to searching, reading and using scientific literature, and to forms of research collaboration, e.g. networks and environments. Students also need to develop the ability to conduct unscripted laboratory experiences, i.e. an experiment that includes the design, set up, collection and analysis of data, and formulation of conclusions. Details of how to proceed with the experiment are not provided to the student, but instead the student is expected to formulate their own experimental plan. This provides them with a student-centered learning experience that is not typically delivered through traditional scripted laboratories.

Evidence
- Junior research projects
- Assessment through student conferences
- Students assigned to research labs and projects
- One or more teaching and learning activity that involves open-ended experimentation
- Student independence in the planning of the experiment
- Learning environments that support open-ended experimentation on a specific problem, process or phenomenon
- Student research assistant internships

Figure 6. Research-integrated education standard
**Workplace and community integration standard**  
(Hughes, 2004; Jonassen et al., 2006; Jamison et al., 2014; Jonassen, 2014; Henriksen, 2014, Eckert et al., 2015)

Engineering programs that actively develop their graduates’ abilities to identify and address authentic and open-ended problems, in authentic settings, interacting with stakeholders.

**Description**
A curriculum that is permeated with learning experiences in which students address real and open-ended problems in workplace or community contexts, interacting with relevant stakeholder groups. The aim is to develop students’ ability to interpret needs and formulate problems that can include multiple and often conflicting goals, contextual constraints and criteria, and require transdisciplinary approaches as well as collaboration and dialogue in various compositions. The aim is also to support students’ mature reflection on their role and responsibilities as engineers, and on the implications of science and technology in society.

**Rationale**
Together with the acquisition of disciplinary knowledge and personal, interpersonal and product, process and system building skills, students also need to develop the ability to apply these in realistic settings and conditions. To prepare graduates for engineering practice, students need experience of working in authentic settings, addressing authentic needs, and interacting with various stakeholders. At least some of this learning should be experience-based, i.e. not only learning *about* such work in theory, but also learning from working in relevant roles in authentic settings. Development of technology is increasingly based on intensive dialogue and collaboration with problem stakeholders, e.g. users, and therefore it is important to practice various forms of communication and collaboration, also with people who are not engineers. Further, if the education communicates an unnecessarily reductionist view on problems and methods for addressing them, graduates may come to see engineering only as creating purely technical solutions to purely technical problems. Education must prepare students for working with problems that may also contain political, economic, social, legal, ethical, and aesthetic aspects, often resulting in conflicting values, conditions, constraints, and criteria for evaluating alternative solutions.

**Evidence:**
The program contains opportunities for relevant learning activities, for instance through:
- Work-based learning experiences
- Co-op educational models
- Challenge-driven education
- Needs-driven projects
- Applying user involvement methods
- Community service projects
- Reflection on such experiences

**Figure 7. Society and workplace-integrated standard**
**Sustainable development standard**
*(based on Enelund et al. 2013)*

A program that identifies the ability to contribute to a sustainable development as a key competence of its graduates. The program is rich with sustainability learning experiences, developing the knowledge, skills and attitudes required to address these challenges.

**Description:** The curriculum features sustainability learning experiences on basic as well as advanced level. Sustainability is addressed both in dedicated course(s) and as integrated learning experiences included in disciplinary courses and projects. The curriculum offers opportunities for students to specialize in sustainable development on the advanced (master) level.

**Rationale:** To address the issues of sustainability is a key challenge for mankind. Engineers need to understand the implications of technology on social, economic and environmental sustainability factors, in order to develop appropriate technical solutions as well as to collaborate with other actors in addressing sociotechnical issues.

**Evidence** may include, non-exclusively, one or more of the following:
- Specific and detailed program learning outcomes address social, economic and environmental sustainability
- Specific course learning outcomes address social, economic and environmental sustainability
- Curriculum with dedicated sustainability courses as well and integrated sustainability learning experiences
- Documented progressive sustainability learning sequences across several courses and projects
- Master programs offering opportunities to specialize in sustainability

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*Figure 8. Sustainable development standard*
DISCUSSION

Are optional standards necessary?

Several of the optional standards above are related to particular learning outcomes, already represented in the CDIO Syllabus. It can therefore be argued that the relevant learning outcomes can be included and elaborated in programme objectives, and implemented already through the “basic” standards or in “conventional” ways. That is of course true, and such normal level of implementation may be sufficient for many, if not most, programs. However, it does not make it unnecessary to explicitly address their implementation in the standards. First of all, we find that when these aspects are taken seriously, they may all necessitate particular forms of education, in multiple courses. We see a parallel in Standard 5 Design-implement experiences and 6 Engineering workspaces, which explicitly address how to realize the activities in the curriculum for learning a particular set of key skills (among them 4.3-4.6 in the Syllabus), while in theory they could have been addressed through standard 7 Integrated learning experiences, and 8, Active and Experiential Learning. Further, we recognize that instead of just listing the related learning outcomes among others, institutions often have legitimate needs to make these aspects highly visible. An official declaration to include any of these optional standards implies a clear commitment. Not only does it communicate a profile, but it also creates impetus through identifying directions for change and direct monitoring through self-evaluation.

Relationship between standards

To some extent the optional standards are overlapping with each other, and with existing standards. It would for instance be fully possible to devise a project-based learning activity according to Standard 5, which also addresses one or more optional standards. The intention is not, however, that a few curriculum elements can tick all the boxes.

We further find that the adoption of any of these optional standards may slightly change the interpretation of other standards. For instance, any of the optional standards will imply a need to develop the relevant faculty competences, i.e. regarding what to teach, Standards 9 Enhancement of faculty competence, and regarding how to teach, standard 10 Enhancement of faculty teaching competence. While this may require substantial effort, we have not proposed a new faculty development standard accompanying each of the optional standards. Instead, we suggest that such needs could be accommodated through reinterpretation of standard 9 and 10, without changing their current definitions.

Deciding on optional standards

We propose that the principles suggested here for expanding the standards, as well as the formulations of the first optional standards, should be subject to discussion within the CDIO community, and to be recognized as official they should be submitted for approval by the CDIO Council. A similar process should apply to any collaborators who want to suggest additional optional standards. Over time, one or more of the optional standards may well prove to be so broadly accepted, that an amendment to the “basic” standards could be warranted.
Using optional standards to strengthen the CDIO community

We anticipate that the optional standards can create meeting points within the CDIO community for educators with special interests, both those who are keen to learn more in order to take their first steps, and experienced implementers who are interested in sharing and developing their practices. This may serve to advance the CDIO community as a natural arena to widely disseminate important work within engineering education.

CONCLUSIONS & FUTURE WORK

Emerging and evolving expectation on the competences of graduating engineers as well as new pedagogical approaches and tools motivate the extension of the CDIO framework with “optional” CDIO standards. The paper shows that a number of potential optional CDIO standards can be identified and formulated in a similar fashion as the existing basic CDIO standards.

The optional CDIO standards can be useful for a CDIO program to clarify its pedagogical profile, beyond the basic CDIO program characteristics. Optional CDIO standards also serve the purposes of structuring knowledge sharing within the CDIO Initiative and may guide the development of the CDIO framework.

The selection and formulation of the proposed optional CDIO standards should be considered as first drafts, to be further evaluated and refined through discussions in the CDIO Initiative prior to acceptance.

REFERENCES


BIOGRAPHICAL INFORMATION

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EUROPEAN INITIATIVE ON CDIO IN RAW MATERIAL PROGRAMMES

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ABSTRACT

One of five Knowledge and Innovation Communities (KICs), was launched in Europe in 2014 and has its focus on exploration, extraction, mineral processing, metallurgy, recycling and material substitution of raw materials. To reach the vision, where the European Union’s industrial strength is based on a cost-efficient, secure, sustainable supply and use of raw
materials, a new generation of skilled people entering industry, universities and research needs to be developed. Today's technical MSc graduates in raw materials and especially primary resources (i.e. exploration, extraction, mining and mineral processing and metallurgy) best suits large companies where they often act as specialists and experts. For small to medium enterprises as well as for our future engineers other skills than technical are necessary. As a part of the KIC Raw Materials, the education project “The implementation of CDIO in raw material programmes” started in 2016. The project focuses, during 2016-2017, on (WP1) faculty- and (WP2) pilot case development. There are no academic institutes in Europe that have yet applied CDIO for primary resource related MSc programmes. This paper describes an education project within the KIC Raw material and presents key outputs with implementing CDIO in mining and metallurgy related programmes.

KEYWORDS

Faculty development, program development, raw materials, Standards: 1, 2, 9, 10

THE KIC IN RAW MATERIALS

The mission of the European Institute of Innovation & Technology (EIT) is to foster entrepreneurship and innovation across Europe. To fullfill the mission, EIT have until 2016 brought together five Knowledge and Innovation Communities (KICs). One of these KICs, was launched in 2014 and had a focus on the raw material chain, i.e. exploration, extraction, mineral processing, recycling and material substitution. The KIC named EIT Raw Materials is supported by more than 100 partners from industry, research and universities. To reach the vision, where the European Union’s industrial strength is based on a cost-efficient, secure, sustainable supply and use of raw materials, a new generation of skilled people entering industry, universities and research needs to be developed (EIT Raw Materials, 2017). All learning and education activities in the KIC Raw Materials are under the umbrella of the Raw Materials Academy. The Academy was created in order to stimulate education and lifelong learning activities and foster new ways of learning and teaching with special focus on the strengthening of innovation and entrepreneurship in the whole raw material chain. The expression “T-shaped” student (Word spy, 2017) is used by the academy and means to educate professionals with an understanding of the full raw materials value chain and with a mind-set for innovation, and entrepreneurship focusing on sustainability. For a schematic view of a T-shaped professional in raw materials, see Figure 1.
EIT Raw Materials have announced for calls since 2015 and within learning and education the calls have had a focus on PhD-, MSc- and Lifelong education as well as wider society learning. One of the six on-going MSc projects is the implementation of CDIO in raw material programmes (Master Education projects at EIT Raw materials, 2017). There are no academic institutes in Europe that have yet applied CDIO for raw material related MSc programmes. To successfully implement CDIO the university itself, programme responsible and the teaching faculty need to be committed (Chuchalin et al., 2015). Once you have committed staff, the mobility and collaboration between universities and exchange of past experience is likely to drive the CDIO implementation (Loyer et al., 2011, McCartan et al., 2016). By EIT Raw materials funding the partners in the project will have a great opportunity to get the university committed and faculty involved to discuss and cooperate during the implementation of CDIO.

PROJECT DESCRIPTION

The raw material chain can be subdivided into primary (exploration, extraction, mineral processing and metallurgy) and secondary (recycling and material substitution) resources. The main thematic content in this project is primary resources where the stages in the life of a mine are expressed in Figure 2. The exploration phase can be subdivided into reconnaissance and detailed exploration where each of these steps takes between one and five years. Hence often the establishment of a mine does not start until three to eight years after finding a mineralization. The development work, which often takes two to five years, concerns mining rights, financing, roads and transport systems, surface plants, shafts etc.
The mining production, which is a process itself, needs to last more than 10-30 years in order to be economically sustainable. The final stage, which often takes one to ten years, is mine closure and restoring the mining area to an acceptable state of safety and environment. In each stage in the life of a mine it is important to simultaneously be aware of all the other stages in order to be an entrepreneurial and innovative engineer.

Figure 2. Stages in the life of mine.

Existing MSc programmes which are linked to the thematic Raw Material content are often very technical or based on geoscience and students graduate as professionals who know how to solve pre-defined and often non-realistic problems. The students are not fully aware of the stages in the life of a mine and how their work will be affected by other parts in the raw material chain. These technical MSc graduates best suit large companies where they often act as specialists and experts. For SMEs other skills than technical are necessary and warranted in order to be productive from the first day. In addition new smart technologies require a change in the traditional skill-set. Students in such programmes seldom (or never) practice entrepreneurial, communication and innovation skills.

The project focuses on faculty and program development. The project has two work packages on-going, since April 2016, with focus on i) teaching the “technical” faculty through CDIO linked courses (entrepreneurship, business etc.), communicative work-shops, inspiration guest lectures and on ii) curriculum, program and course developed together with the industry.

The consortium for the project covers the whole knowledge triangle with one partner from a research institute, two from industry and five from academia. Looking at mobility, the partners cover a large part of Europe, from Sweden, Germany, Ireland and Spain. Luleå University of Technology (LTU) is the coordinator of the project and has a long track record as a complete mining university covering all aspects of the raw material value chain including non-technical issues. Research and study programs for the whole range from Raw Materials to Material Sciences is also covered by Clausthal University of Technology (CUT) and Technical University of Madrid (Universidad Politécnica de Madrid - UPM). At both UPM and Delft University of Technology (TU Delft), some engineering programmes have already implemented CDIO and can therefore act as a supporter when implementing CDIO in the raw material resource and mining engineering field. Chalmers University of Technology (Chalmers) was one of the four original universities behind the CDIO initiative. In this project, Chalmers has a role as developer of CDIO courses for the faculty as well as course
development within processes around production of rock materials. The University of Limerick (UL) will have almost the same role as Chalmers in this project, as material and processes are one of their specializations. The industry as well as research institute partners (i.e. Luossavara-Kiirunavaara Aktiebolag (LKAB), RUSAL Aughinish Alumina and SP Technical Research Institute of Sweden) will bring in real cases from the industry and act as advisors for WP1 and WP2.

**Work package 1 – Faculty development**

WP1 has been focused on faculty development (CDIO Standard 9 and 10) with faculty courses developed and given by the Chalmers and Limerick universities during 2016 and will be given at Delft in May 2017 (Bhadani et al., 2017). The aim of WP1 is to create a faculty course both containing the CDIO approach as well as examples and cases from the raw material sector. Hence in the final faculty course in October 2017, the programmes and courses that have been developed in WP2 will be presented.

Inspirational lectures linked to CDIO have been included in WP1 in order to get the work started and faculty interested in the subject. The first inspirational lecture was given in Madrid in May 2016 and the second in the end of September 2016 in Clausthal. After each inspiration lecture, the project coordinator at LTU briefed the audience on how this can be implemented in our raw material programmes. The major inspirations from the lectures and the inputs that the partners thought they should use in their continued work was to focus on the student contribution instead of the teacher contribution and to use a variation in assessment methods instead of only written exams in the whole program.

Participation at the EIT Academy driven workshops, such as the entrepreneurial workshop at Uppsala University in March 2016, has been a part of WP1 as well. In entrepreneurial schools it was obvious to have a lab for students to foster creativity and innovativeness. The discussions at the workshop regarded lab for raw material students as well as how to engage SME and start-ups in our programmes. To add the possibility for networking and see how others are working with CDIO, programmes and courses, the participation at international CDIO conferences has also been included in WP1.

A transfer from “a standard package” from business and entrepreneurial schools to a content that is specific for our sector is warranted by the RM Academy and made possible by this project. Business and entrepreneurial schools exist at most universities, but these often deliver a "standard package" of project and courses that are not specific for the Raw Materials sector. The universities offering programmes and courses in the RM sector are, as part of EIT Raw Materials, expected to include innovation, entrepreneurship and business skills, in their MSc programmes. The win-win situation of this work package is that the “technical engineering” faculty will be taught CDIO linked courses and that the “entrepreneurial” faculty will be taught exploration, mining, mineral processing and metallurgy related issues.

**Work package 2 – Pilot case development**

As the vision is that the university partners include entrepreneurship and innovation in their typical technical engineering programmes, it is important to begin with creating a few EIT RM CDIO pilot cases. For each and every partner the situation and possibilities for CDIO-implementation is unique. Therefore the pilot case development in WP2 will be both on programme and course level.
Since all partners have had a unique prerequisite and starting point the development work has been different. MSc programmes with focus on primary resources and mining are given at LTU, CUT and UPM. The development of the first pilot case with focus on mining started at LTU and will be based upon the industry needs and practical problems and real cases with input from LKAB. Hence at LTU the work during 2016 focused on engaging industry (Standard 2) in program objective and development work (Edelbro et al., 2017) as well as on constructive alignment (Biggs & Tang, 2011) in courses. The result of the work will help to set the context of the programme (Standard 1).

The focus at CUT has been and is on course development within the international MSc Mining Engineering. The main focus has been on courses in mine ventilation (Clausen, 2017), the integration of sustainability aspects in Mining Engineering Education (Binder et. al., 2017) and the implementation of underground mines as innovative learning spaces (Clausen et al., 2017). The focus at UPM has also been on course development at the School of Mines, with the collaboration of professors of the School of Industrial Engineering as advisors. For the course development at UPM, the participation of an external institution for student practices on machinery has also been scheduled. Courses within primary resources are also given at Chalmers, UL and at Delft and are under development work.

DISCUSSION

The CDIO Initiative was based on mechanical and design engineering but is suitable for programs in all fields of engineering (Crawley, 2001). However the acronym does not fully connect to raw material related programmes if it symbolizes what engineers do in raw materials. To explain the acronym to people working in raw materials might require time and effort without conveying the message that CDIO is meant to strengthen the professional side of engineering education. Mining engineers do not talk about products, they talk about processes. Mechanical and design engineers determine stress and load and select material with well-known properties based on strength, weight and price. In mining the stresses are already there and they, as well as the material properties, need to be determined. Hence the different disciplines deal with material from different perspectives. It is also worth mentioning that people working with exploration often has a geoscience background and are not so often engineers. These might be reasons why CDIO has not been implemented in primary resource programmes before.

The primary resource industry is not the number one and most attractive sector for an 18 year old student. With another attitude regarding the context of the programmes and by having programme development work validated by stakeholders the programmes might get more attractive. Since this project has partners within the whole knowledge triangle (industry, research and academia) the programmes have the possibility to include more real and complex problems. Therefore, it is positive that students and teachers can act as ambassadors of the programmes and with new ambassadors trained every year.
OUTPUTS BY THE PROJECT

Four different events for the faculty, with in total more than 110 registrants, have already been created in the project. The events took place at different countries and locations which made it possible for many partners to attend. For the pilot case development 11 stakeholders from the industry were involved as well as faculty at the different universities. Hence more than 30 people were directly involved in programme and course development.

Through WP 1 and WP2 new teaching methods and pedagogic tools have started to be used in the raw material MSc programmes. The inspiration comes from lectures, CDIO conferences, the developed CDIO cases and faculty courses. The faculties at the universities are now a part of a large pedagogic network through CDIO as well as a large network within the discipline. As a result we will see modified courses and programmes and new developed curriculum with clearer learning outcomes. In total the implementation of CDIO will influence and inspire more than 150 students within primary resources programmes and it will also involve more than 50 faculty members.

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**Elisabeth Clausen** graduated in Mining Engineering at Clausthal University of Technology and obtained her PhD degree in the area of Underground Mine Planning from the same university. Since 2013 she is working as Akademische Rätin at the Institute of Mining as Clausthal University of Technology. Dr. Clausen is deputy head of the Department for Underground Mining Methods and Machinery as well as lecturer in the field of Mine Ventilation and Climatisation as well as Software for Underground Mine Planning at Clausthal University of Technology. She was awarded by CUT in 2014 and the Society of Mining Professors in 2016 for Innovation in Teaching and Learning.

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DESIGNING A FLEXIBLE, CHOICE-BASED, INTEGRATED, PROFESSIONALLY CHALLENGING, MULTIDISCIPLINARY CURRICULUM

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The Hague University of Applied Sciences,
Faculty of Technology, Innovation and Society,
Industrial Design Engineering [Open] Innovator & Research group Sustainable Talent Development

ABSTRACT

In a lifelong learning society students need to deal with the responsibility to give their learning path direction, find motivation, and prove what they have learned. What pedagogics and what kind of didactic structure do you need to bring this about in higher education? What does it mean for the professionality of the teaching staff, the organization of the teams, and the needed facilities? A co-creational approach is applied in redesigning the curriculum of the undergraduate programme Industrial Design Engineering [Open] Innovator, which offers multidisciplinary projects in authentic learning environments, and caters for the professional profiling needs of our future students. Teaching staff, students, alumni, future students, industry (including the social profit sector), and educational scientists collaborate towards the flexible, integrated and choice-based ‘Project M(odular) Curriculum’. This paper describes the arguments for the choices made from an educational point of view, taking the twelve CDIO standards and CDIO syllabus as a blue print. In certain standards, project M goes beyond the framework to fulfil the needs of stakeholders, take the newest useful (engineering) educational research outcomes into account, and come to a curriculum design that will be adaptable and versatile enough to hold value for the coming ten years at least.

Based on the experiences of Project M, considerations on refining CDIO standards 5, 8, 11 and 12 are presented in the discussion, together with a rationale to add a rubric score to the CDIO self-evaluation, and the discussion of minor gaps in the CDIO syllabus.

KEYWORDS
Flexible curriculum, choice-based modular curriculum, professional identity, curriculum design, multi-disciplinary education, standards: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12

INTRODUCTION

There are two flexible curriculum initiatives within CDIO member Faculty of Technology, Innovation and Society (TIS) at The Hague University of Applied Sciences (THUAS). One of them concentrates on making it possible for students to choose courses at the affiliated
programmes within the cluster along the way. In this way, the 4-year bachelor programmes Climate and Management, Building Engineering and Civil Engineering are developing one joint ‘Building Environment’ nodal curriculum. Based on individual choices students pass by a number of nodes and in between learning takes place in professional, mixed-discipline, guided tasks. The other initiative concentrates on parallel course choices for students within the international 3-year bachelor programme of Industrial Design Engineering [Open] Innovator (IDE): a choice-based modular curriculum. Here also the professional, guided task and mixed-disciplinary teams are points of departure. Students will learn in a societal, authentic context, together and reciprocally with stakeholders from the professional field including users and (a hybrid) teaching staff. The IDE teaching staff refers to the development of this curriculum as Project M(odular), and approaches and executes it as a co-creational design process together with students, alumni, educationalists and industry.

**REASONS FOR THE IDE CURRICULUM REDESIGN**

The Industrial Design Engineering [Open] Innovator (IDE) curriculum is an international 3-year bachelor’s programme. It is taught in English and about five years old. It teaches students the Industrial Design Engineering competencies with a focus on the fuzzy front end of innovation, sustainable development and impact in the realization phase. After the first students graduated two years ago an evaluation was done, and the quality of their learning results was compared with the principal pillars of the IDE curriculum: Design, Research, and Entrepreneurship. Entrepreneurship proved to be underrepresented. Several other aspects came to light in evaluations about the quality of the modules (10 week periods in which students do a project and have supportive theory and skills courses) and about the level of the graduation projects, see Table 1.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Rationale</th>
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<tbody>
<tr>
<td>More attention for entrepreneurship in programme.</td>
<td>Graduates do not show enough entrepreneurship (either in attitude, or entrepreneurial projects)</td>
</tr>
<tr>
<td>The minor Entrepreneurship in Innovation should move to major.</td>
<td>It is important, and Entrepreneurship is already underexposed. Also, mandatory minors are basically major education to begin with.</td>
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<tr>
<td>Internship is missed in programme.</td>
<td>During internship students learn about the norms in the professional fields, e.g. level of finishing deliverables, graphic design etc.</td>
</tr>
<tr>
<td>IIR (International Insights Research): 12 EC is too little</td>
<td>If it were to be at least 15 EC, students could get external grants for their travel abroad.</td>
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<tr>
<td>Build in ‘free space’ for interesting projects that are offered during the school year.</td>
<td>With no room for electives in the programme, flexibility to participate in interesting projects disappears. Often students’ motivation typically increases after doing competitions, projects like Bamboo city etc.</td>
</tr>
<tr>
<td>Restore balance in the programme.</td>
<td>First year students complain it takes too long before they can start to design something. Second year students complain the 2nd year is much heavier than the first year.</td>
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The curriculum commission, responsible for the quality and contents of the programme, looked into the possibility to make small adjustments to the current programme to fix these things, but found that was not possible. A reshuffle of the elements of the current programme was investigated and this seemed more promising, but it was challenging to cram it into 3 years (basically 2 years, as the third year is filled with a 30 EC (European Credit, ECTS system) minor and 30 EC graduation project). Thus, the idea for a choice-based, modular
approach in the curriculum was born to prepare our curriculum to flexibly fit our vision on future education: Project M.

**Collateral and strategic advantages and opportunities of project M**

The choice for the modular approach offered several opportunities: a mix of strategic, procedural, pedagogic and didactic drivers, see Table 2.

<table>
<thead>
<tr>
<th>Opportunity</th>
<th>Rationale</th>
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<tr>
<td>Profiling and talent development: Students can develop a professional identity by flexibility in the programme to self-profile: T-shaped, U-shaped or W-shaped</td>
<td>In order to fit in the job market, students need an upside-down T-shaped profile: wide basis of skills with a specialty. When students can function in an interdisciplinary context and can combine 2 or maybe even 3 talents on top of their basis, they even get a U or W shaped profile: hence a multidisciplinary, choice-based programme.</td>
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<tr>
<td>Network learning: Keep project-based, client-involved, active learning elements of programme.</td>
<td>What we have works well, only flexibility needs to be incorporated to be able to take on opportunities for collaboration in the professional field. Every semester students do authentic projects for real clients.</td>
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<tr>
<td>Multidisciplinary: Make a flexible programme so collaborations with other programmes, faculties, research groups, universities and projects/competitions becomes possible</td>
<td>In our programme, there are possibilities to work directly together with other parties within TIS and THUAS, as well as some (inter)national partners. For instance, other faculties have shown an interest in collaborating in entrepreneurship and interaction design semesters. Research groups can provide for projects. Thus, the international classroom becomes a multidisciplinary one.</td>
</tr>
<tr>
<td>Internationalization: Work in modular entities that make the exchange as easy as possible</td>
<td>We are working together with CDIO partners and offering an EPS minor to tap into a different pool of exchange students. Other international contacts: Berkeley (entrepreneurship), Idefix, China etc.</td>
</tr>
<tr>
<td>Didactics: Half year modules with less testing, freedom of choice and more autonomy.</td>
<td>A lot of tests often have not the desired effect, as they compete for the student’s attention, do not offer the learning experience as it should at the end of the course and demotivate from an intrinsic motivation point of view. It elicits the consumerist and calculative attitude more than the active learning attitude. Instead of four separate tests within a week at the end of each quarter, students will now get one integral assessment every five weeks (three per semester). Also, for the next generation, negotiation and making choices are natural but also vital competences. Our education should tap into that autonomy, not take it away for 3 years.</td>
</tr>
<tr>
<td>Positioning: attracting (certain) students to enrol</td>
<td>We have a unique offer in the landscape of IDE programmes in the Netherlands for VWO-students: small scale, freedom of choice, entrepreneurship and world citizenship in a highly international setting, while working for real clients throughout the programme, building up your (career) network right away.</td>
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Based on literature research, trend reports in education, and benchmarking modular design programmes, a co-creation process started in study year 2015-2016. A number of decisions concerning the structure of the new curriculum were made, resulting in Figure 1.

Students can choose their programme from a menu of semesters after completing the first 20 weeks of mandatory programme, ‘the Basics of IDE’. Students can make choices based on the experiences and aroused interests of that half-year to continue to develop talents or work on weak spots, deepen or widen their knowledge and expertise, and steer their experience in the thematic direction they want.
Figure 1. Basic structure of the Project M Curriculum of IDE

Organizationally, the choice-based semesters are 20 weeks each, of which 15 weeks are education and the last unit of 5 weeks is allocated to students’ own bedside table projects, *freespace* projects from teachers, special excursions or international exchanges, portfolio development and resits. For the modular approach to work there should be no entry barriers to a semester (Sinke et. al., 2015). The only requirement is to have passed the introductory and selective Basics of IDE in semester A. A minimum and maximum of students who can enrol is predefined. Semesters can be offered twice a year if very popular. About four to six semesters will be offered per half year once the programme runs on full force. Students enrol for first, second and third choices as the programme cannot always guarantee first choice placement. Semesters have a profile: explorer, creator or entrepreneur, or any combination of these, which helps students to choose. As THUAS works within the major-minor system, one semester can be filled with a minor in semester C, D or E. This minor can but doesn’t have to be unrelated to the IDE programme.

THE PROJECT M CURRICULUM DESCRIBED IN TWELVE CDIO STANDARDS

As mentioned, the designing of the Project M Curriculum is a co-creational process. In the academic year 2015-2016 three co-creation sessions were organized with the IDE teaching staff, students, alumni, future students, the work field and educational scientists. This resulted in an elaborate landscape of semester topics, personas of our (future) students, and brainstormed concept semester designs. With that input a semesters menu, semesters structure sketches, and semester labels could be generated, and again detailed in co-creation in year 2016-2017. Project M’s curriculum design will be explained per CDIO standard. Occasionally the design process goes beyond the CDIO syllabus and standards version 2.0. This is described per standard and serves as input for the discussion at the end of this paper, for future development of the CDIO framework.

**Standard 1 The Context**

“...Adoption of the principle that product, process, and system lifecycle development and deployment -- Conceiving, Designing, Implementing and Operating -- are the context for engineering education. Beginning engineers should be able to Conceive--Design--Implement--Operate complex value-added engineering products, processes, and systems in modern team-based environments. They should be able to participate in engineering processes, contribute to the development of engineering products, and do so while working
to professional standards in any organization. This is the essence of the engineering profession.” (Crawley et. al., 2011)

As Industrial Design Engineering [Open] Innovator (IDE) is a design programme, the life cycle of products and product-service combinations is a central theme. Students are taught beyond conceiving and designing in a theoretical or educational setting by working on real life cases from day one, designing products for real life clients, and including implementation and operation activities such as putting products in the market and truly manifesting themselves in the work field. Clients are industry partners, social domain partners, non-governmental organisations, design agencies etc. Students are expected from day one to show a professional standard of behaviour and results, be it by increasing requirements. That being said, implement and operate are less often touched upon in typical design education. For that reason, some of the new semesters in Project M will focus on those two phases (for instance the semester Design Engineering), using results from C/D projects of other more strategic design semesters. This will empower the innovations thought up within our programme. Students can also set up their own enterprise within the entrepreneurial semester, work on prototyping and testing in others etc. For students to be aware of their choices in this direction, they start right away in the Basics of IDE with operate and implement units of 5 weeks (see Figure 4). This way, students can decide if they want more by choosing one or more of the semesters focusing on the I and O of the design process.

Standard 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 programme goals and validated by programme stakeholders. They [...] are codified in the CDIO Syllabus. Setting specific learning outcomes helps to ensure that students acquire the appropriate foundation for their future. Professional engineering organizations and industry representatives identified key attributes of beginning engineers both in technical and professional areas. Moreover, many evaluation and accreditation bodies expect engineering programmes to identify programme outcomes in terms of their graduates' knowledge, skills, and attitudes.” (Crawley et. al., 2011)

THUAS offers competency-based education, defining the learning outcomes as a combination of knowledge, skills and attitudes. Together with the Dutch twin IDE-programme at THUAS (a 4-year bachelor programme taught in Dutch called IPO) IDE has formulated a comprehensible set of 5 main competencies our students master, see Figure 2.
Figure 2. The competencies of IPO/IDE

This visualization of the competencies shows where each is nested: designing and engineering is hands-on, doing research provides glasses to look through, for organizing and managing students need to develop that frontal lobe of their brains, and learning is a matter of the (motivated) heart. And for all of these communication is important.

Each competency has several sub-competencies:

1. **Do Research**
   1.1. (Re)define problems and reason analytically
   1.2. Discover knowledge by investigating and experimenting
   1.3. Take external contexts into account (societal, environmental, entrepreneurial)
   1.4. Approach research in a (technical and) human-centred way
   1.5. Report on research using a practical scientific standard

2. **Design & Engineer**
   2.1. Formulate design briefs containing vision and requirements, based on primary and secondary research
   2.2. Use an iterative process with diverging and converging methods and techniques
   2.3. Integrate human, market, technological, and context values during the design process
   2.4. Consider desirability, viability, and feasibility while designing and engineering
   2.5. Create and optimize ideas, concepts, prototypes, and product proposals
   2.6. Evaluate ideas, concepts, and (end) products based on requirements

3. **Organise & Manage**
   3.1. Work methodologically
   3.2. Collaborate within a design team in a multidisciplinary (international) setting
   3.3. Show resourcefulness, flexibility and willingness to make decisions in fuzzy (complex) contexts
   3.4. Show entrepreneurship or intrapreneurship
   3.5. Practice project, stakeholder, time and resource management
   3.6. Break down and model systems and select relevant approaches

4. **Communicate**
   4.1. Manifest/present yourself in a (semi-) professional setting
   4.2. Communicate within a team on team dynamics and (your) role
4.3. Make deliverables tangible in a refined, communicative way
4.4. Communicate in a foreign language and/or in an international setting

5. Learn
   5.1. Reflect on your role in projects and your impact on society as an innovator
   5.2. Develop and adapt learning strategies
   5.3. Transfer and integrate acquired knowledge and experience in projects

The IDE competencies cover the entire Dutch national professional profile for IDE programmes in higher education, the Dublin Descriptors, and the CDIO Syllabus’ learning goals (see Table 3). This includes the later addition in version 2.0 of the learning goals Leadership and Entrepreneurship.
Lawson & Dorst (2009) recognize different levels of expertise in design students, from a novice who can apply strict rules, via an advanced beginner who relies on general truths and can make connections, to a competent graduate who is a problems solver, learner and reflector able to adopt when needed, see table 4. These levels of expertise coincide with Feisel’s Taxonomy (Feisel, 1986) and are used to specify the IDE Competencies, by providing students with a rubric of the sub-competencies on those three levels. The active verbs of Bloom’s taxonomy are used in the sub-competencies and rubric-cells (Felder & Brent, 2004).
Table 4. Three levels of competency.

<table>
<thead>
<tr>
<th>Lawson &amp; Dorst</th>
<th>Novice</th>
<th>Advanced Beginner</th>
<th>Competent</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Follow and apply strict rules</td>
<td>Use of general truths</td>
<td>Problem solver, learning, reflecting</td>
</tr>
<tr>
<td>Feibel's Taxonomy</td>
<td>Define, Compute</td>
<td>Explain</td>
<td>Solve, Judge</td>
</tr>
<tr>
<td>General IPO/IDE interpretation</td>
<td>Checking the boxes</td>
<td>Connecting design steps, reflection</td>
<td>Judging, self-evaluating, reflecting, solving, adapting approach</td>
</tr>
</tbody>
</table>

Beyond the CDIO syllabus 2.0 referred to in Standard 2: Cultural differences and co-creational teamwork

Two elements in our learning outcomes go beyond what standard 2 advises. First of all, the CDIO Syllabus asks for teamwork, centred around a team of equals (fellow students). At IDE students learn how to work in co-creation teams with real stakeholders right away, including industry partners and users. And secondly, as most students are communicating daily in a foreign language (English), the learning goals for working in an international setting are more elaborate than the CDIO syllabus, focussing on teamwork while taking cultural differences into account both in process and results.

**Standard 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. Faculty play an active role in designing the integrated curriculum by suggesting appropriate disciplinary linkages, as well as opportunities to address specific skills in their respective teaching areas. An explicit plan identifies ways in which the integration of skills and multidisciplinary connections are to be made, for example, by mapping the specified learning outcomes to courses and co-curricular activities that make up the curriculum.” (Crawley et. al., 2011)

Figure 1 showed the structure of the curriculum. Each semester has a central, authentic project (a design or design research). Therefore, in each semester all main competencies will be addressed. In these competencies, disciplinary learning goals are already intertwined with personal and interpersonal skills. Because of the parallel choices, students each create their own path in the curriculum. Hence the explicit plan doesn’t look like set lines throughout the courses offered in time. Instead a picture such as Figure 3 appears.
Standard 4 — Introduction to Engineering

“...An introductory course that provides the framework for engineering practice in product, process, and system building, and introduces essential personal and interpersonal skills. Introductory courses 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. Students usually select engineering programmes because they want to build things, and introductory courses can capitalize on this interest. In addition, introductory courses provide an early start to the development of the essential skills described in the CDIO Syllabus.” (Crawley et. al., 2011)

In the Netherlands, the first year of a study programme is named the propaedeutic. By law it needs to be the introduction to the whole area of study/profession and it needs to be selective. At THUAS students even get a propaedeutic diploma after the completion of all its courses and projects, together worth 60 EC.

Within Project M the introduction and selection elements are offered in the mandatory Basics of IDE semester, see Figure 4, and the first choice-based semester. The basics are offered in four units of 5 weeks, in all three profiles of IDE ‘explorer’, ‘designer’ and ‘entrepreneur’, and with a focus on all four stages of a CDIO design process. As one can see, the C and D are exchanged. First of all, 80% of our students come from abroad and need this first unit to get used to many things. Working with your hands on a prototype in the workshop is a nice change from all the thinking that is involved with that acclimatisation process. Also, in this first ‘creator’ unit, students will start calculating and constructing right away, testing their findings with their prototype. This gives them a clear introduction to the engineering part of the programme. And third, during the co-creation process current students indicated they...
wanted to do the designing right away when they entered the programme, as it fit their
preconceptions of the profession best. The blue blocks are project coaching, and pink and
yellow are supportive theory and skill classes for the project. Everything orange is integrated
assessment and the yellow blocks are portfolio time.

Figure 4. The Basics of IDE Semester, the first compulsory 20 weeks of the IDE programme.

**Beyond Standard 5: International, Multi-disciplinary 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.” (Crawley et. al., 2011)

An IDE student has a conceive-implement, design-implement, or design-operate experience
every semester of the major programme. What IDE added to standard 5 is to offer students
international and multi-disciplinary experiences during these semesters. Because of the
international classroom at the IDE programme (over 80% of students come from abroad),
every semester could be seen as an international experience, but students also have the
opportunity to go abroad to do a design or design research project, an exchange, or a minor
elsewhere. The semesters are open to incoming exchange students as well. Some semester
projects will be taken up by IDE students together with students from other disciplines such
as mechanical engineering or non-engineering disciplines (health, social work etc.) from our
own or one of our partner universities. This ensures an actual multi-disciplinary context for
our students already during their studies.

**Standard 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.”
(Crawley et. al., 2011)

In the current IDE workspace lecturers and students share one big room with a large metal
whiteboard wall for creative processes, office desks and student work tables, which is
located next to the workshop. The university is in the middle of a refurbishing process of the
30-year-old building. This has given the faculty the chance to communicate the CDIO
principles and plea for semi-professional labs, design studio spaces, and a professional reception area for clients. Lecture halls are used minimally by IDE, about 2 hours per week. When the refurbishing is done, students will have access to active learning labs such as ‘project group landscapes’ with group tables, video screens and lockers for project work, where they can sit and work in teams, meeting rooms where project stakeholders including tutors can come and visit, and an extended workshop and 3D printing lab.

**Standard 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. [This] can be realized only if there are corresponding pedagogical approaches that make dual use of student learning time.” (Crawley et. al., 2011)

Each semester is an integrated learning experience. The question is how to gradually increase the authenticity and complexity of the professional learning tasks, and the autonomy and self-direction of the student. Personal and interpersonal skills are interwoven with disciplinary knowledge and together offered within different contexts that prepare students for the complexity that awaits them in the professional field. But in our philosophy to educate ‘engineers who can engineer’ it is not enough to merely offer the authentic, professional context following John Dewey’s theory of experiential learning (Fransen, 2005) and restore reflection in engineering education (Buch & Bucciarelli, 2015). When one ‘throws students in at the deep end of the pool’, as a Dutch saying goes, with minimally guided instructions for ‘increased authenticity’, this does not fit the cognitive architecture of our students’ brains when they come in at age 17-19 (Kirschner et al, 2006). Kirschner found evidence for a higher effective learning by guided, just-in-time instruction, in order to deal properly with expert-novice differences and critical cognitive load. This led to the semester structure as seen in Figure 5, where workshops offer just-in-time supportive theory and skills to the project groups, and together with the project tutoring offer the students the structure so work on the authentic design challenge of the semester. Also, regular coaching sessions are provided (the violet blocks), so the students are scaffolded in learning to define their own professional profile and prove their mastery of the competencies along the way via a development and professional portfolio.
Figure 5. Structure sketch of the Project M choice semesters.

Beyond standard 8: Not Just Active Learning for Life Long Learning.

“...Teaching and learning based on active experiential learning methods. By engaging students in thinking about concepts, particularly new ideas, and requiring them to make an overt response, students not only learn more, they recognize for themselves what and how they learn. This process helps to increase students' motivation to achieve programme learning outcomes and form habits of lifelong learning.” (Crawley et. al., 2011)

Active learning has long been a priority of THUAS. Because of the design-focused engineering education at IDE and IPO experiential learning has been the focus in teaching methods. Applying active learning techniques in lecture hall settings is still a field of development, for those scarce moments IDE offers lecture hall classes. However, next to active learning there are more important didactical choices to encourage the lifelong learning abilities of our students by increasing motivation. One is making them familiar with blended learning during their studies, in a ‘flip the classroom’ set up, using several suitable platforms. Another is giving room for autonomy, from the perspective of self-determination theory (Gagné & Deci, 2005). When students can show autonomous behaviour, they voluntarily function and take on working or learning tasks. In a lifelong learning setting, which will not always be a formal educational setting with grades and credits as extrinsic motivators, this is vital. IDE likes to give students the chance to tap into their personal drivers during that stage, by letting them choose their own path via the semester menu and build up their own professional identity. Meijers et. al. (2010) identified three main conditions for developing a professional identity: learning should take place in an authentic setting, students should have the opportunity to choose part of their study activities according to their personal developing goals and there should be a professional, reciprocal dialogue between students and teachers about their development. The latter is addressed in the core values of our programme: Creative & Curious (think divergent), Experimental & Integrated (iterative approach), Structured & Critical (keep improving), Inspiring & Convincing (in communication), People Planet Prosperity Partnership Peace & Future Oriented (be engaged). Not only are the core
values used to describe attitude components in learning, they are also practiced as preached by the staff in their interaction with students.

**Standard 9 Enhancement of Faculty Competence and Standard 10 Enhancement of Faculty Teaching Competence**

“...Actions that enhance faculty competence in personal and interpersonal skills, and product, process, and system building skills.” “...Actions that enhance faculty competence in providing integrated learning experiences, in using active experiential learning methods, and in assessing student learning.” (Crawley et. al., 2011)

Once TIS became a CDIO member, an internal, informal professional learning community around CDIO was started. Several workshops by CDIO-gurus, a CDIO-experimentation work group for lecturers of the 12 different programmes, and a teaching staff training in Active Blended Learning have been initiated. IDE teaching staff has taken part in several of these initiatives, working on constructive alignment of teaching, learning, and assessment. Part of them are hybrid teachers, designing or doing research next to teaching, or both. As Industrial Design Engineering is a multidisciplinary field on its own, combining engineering with design, cognitive psychology, ergonomics and business, the members of staff who studied IDE themselves are familiar with working multi-disciplinary. Yet society sees a changing role of the 21st century teacher, not as expert on a certain specialization only, but as co-designer in an open innovation network setting, facilitating innovations by reciprocal learning of all stakeholders including the students (Hallenga-Brink & Vervoort, 2015). The co-creation of the Project M Curriculum offers the opportunity to work on enhancement of faculty (teaching) competences at the same time, which is necessary to innovate the curriculum design.

**Beyond standard 11: Student ownership to prove learning goals, less assessment and formative entry level testing**

“...Assessment of student learning in personal and interpersonal skills, and product, process, and system building skills, as well as in disciplinary knowledge... Different categories of learning outcomes require different assessment methods. These methods may include written and oral tests, observations of student performance, rating scales, student reflections, journals, portfolios, and peer and self-assessment.” (Crawley et. al., 2011)

Current IDE student have 4 exams in week 8 and 9 of every 10-week module, plus resits of the former module in week 10. It can be written exams, handing in reports or portfolios, presenting project work or a combination of these. Each exam has a list of 5-10 learning goals. Cohen-Schotanus (2010) proved in her research of multiple cohorts of medical students that students typically start preparing for a written exam three weeks before the deadline and study hardest for the first test they have, to the disadvantage of the remaining assessments in the same test week (see also Schmidt et. al., 2009). At IDE teaching staff indeed sees the quality of project work decrease when written exams are planned around the same time. Therefore, in the Project M Curriculum semesters purposefully have a 5-week unit structure, see Figures 4 and 5. During the first week of the semester students participate in a benign pressure-cooker kick-off session, which function as a formative entry-level test, to discover how far they get based on what they already know. This shows them how they can benefit from supportive theory and skills workshops offered throughout the semester. Each 5-week unit is concluded with one integrated assessment only, in which students have the responsibility themselves to prove on which level they master a self-chosen selection of six
sub-competencies/learning goals, using their project and workshop work as proof. Three assessment methods are aligned with the type of sub-competencies students have to prove and the offered learning activities during the units: handing in a specific deliverable with supportive process steps that led to it, explain the process in an oral exam while showing the steps taken, or reflect in an oral exam on the observations made by project tutors and workshop lecturers during the unit. Assessors are always grading in duos: the student’s tutor and an independent assessor.

**Standard 12 Beyond Programme Evaluation**

“...A system that evaluates programmes against these twelve standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement... Evidence of overall programme value can be collected with course evaluations, instructor reflections, entry and exit interviews, reports of external reviewers, and follow-up studies with graduates and employers. The evidence can be regularly reported back to instructors, students, programme administrators, alumni, and other key stakeholders. This feedback forms the basis of decisions about the programme and its plans for continuous improvement.” (Crawley et. al., 2011)

IDE has done the first self-evaluation on the 12 standards in 2014 and the second in 2016. Current regular programme evaluation cycles for multiple stakeholders around the programme, plus extra evaluations for accreditation purposes, help pinpoint the evidence for the self-evaluation. Because CDIO is integrated in the project M curriculum redesign, the evaluation automatically takes CDIO-principles along.

Instead of developing plans and implementing them and then ask industry to evaluate this, IDE has taken the route to co-create the new curriculum in a group of teaching staff, (prospective) students, alumni, industry, educationalists, and other stakeholders. During the semesters evaluations with students, clients and teaching staff will help to adapt while teaching, and make plans for the next run. This co-creation setup results in not only feedback afterwards, but also feedforward and feedduring.

**DISCUSSION**

A top score of 5 in the rubric of the CDIO self-evaluation on the 12 standards is geared towards stakeholder evaluation and review of plans and implementation. When involving industry, students and other stakeholders in this way it is a common challenge to truly close the PDCA-cycle and let stakeholders benefit from the evaluation findings directly, and not only the next cohort or next project. The development of the Project M Curriculum shows that by co-creating with the stakeholders from day one onwards, acknowledging the needs, making plans, execute them, finding evidence and evaluating the results together, one can offer a solution for this challenge. Simultaneously, it elicits reciprocal learning between all stakeholders during the process, enhancing faculty competency in the professional field and faculty teaching skills for the 21st century (CDIO standards 9, 10) and a better understanding of education and coaching by the professional field. The suggestion could be considered to let co-creation with the stakeholders on the standards be a score 6 in the rubric.

Secondly, standard 5 could be enhanced by making at least one of the design-implement experiences multi-disciplinary. That way students learn to work together with other types of engineers before entering the workforce. From an (open) innovation point of view this is what future engineers will encounter in daily practice (Chesborough, 2003).
In this line of thinking, the teamwork learning goals (3.1) of the CDIO Syllabus could be more geared towards co-creation in multidisciplinary teams with interdisciplinary team members, as students need these competencies as well. And the international element can be found back somewhat in learning goal 3.3 “communication in a foreign language”, but not all intercultural competencies are integrated in the syllabus. Internationally oriented CDIO programmes in higher education do see the need to offer them to students.

Standard 8 is called ‘Active Learning’ at the moment. In developing Project M multiple ‘Lifelong Learning Didactic methods’ were applied, such as blended learning and the flexible choice-based professional profiling. Active learning is one example which could fulfil a standard formulated on a higher abstract level indicating its intent better.

Finally, in standard 11 Project M demonstrated a number of requirements around integrated assessment which could improve its quality and success rate, such as putting the responsibility for proving competencies at the student instead of the teacher, integral assessment, formative entry level testing and timing constrains on exam schedules.

CONCLUSION

In innovating the IDE curriculum towards a flexible, choice-based, integrated, professionally challenging, and multidisciplinary curriculum the CDIO framework has proven to be a match to the ambitions of the undergraduate programme Industrial Design Engineering [Open] Innovator of THUAS. As the terms conceive, design, implement and operate are closely related to the realms of an open innovator, they effortlessly found a spot in the structure of the curriculum. The CDIO syllabus 2.0 also fitted to the competencies of an industrial design engineer which were formulated on a national level in 2011 and completed within THUAS with entrepreneurship-elements. And there are more CDIO merits to the IDE curriculum: Collaboration with CDIO partners is set up to offer students the multidisciplinary context they will find in their professional life already during their studies. During open days CDIO shows (prospective) students the international anchors of the programme. The next step is to take our work field network along in our CDIO endeavours.

Several times IDE needed to go beyond the CDIO framework interpretation: in taking student teamwork in the CDIO syllabus to the next level of co-creation for them to become engineers who can engineer, and add intercultural competences beyond communicating in a different language, and by refining several standards (2, 5, 8, and 11). Also, there was a need for a score of ‘6’ in the CDIO self-evaluation rubric when co-developing a standard in co-creation with all stakeholders instead of thinking it up first and then checking with the stakeholders if they would be willing to support. This indicates an opportunity of growth for the CDIO framework. In line with the reciprocal learning that happens in co-creation in multi-stakeholder networks, this paper is an invitation for further investigation and discussion for the continuous development of the framework.
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BIOGRAPHICAL INFORMATION

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THE PEDAGOGICAL DEVELOPERS INITIATIVE - SYSTEMATIC SHIFTS, SERENDIPITIES, AND SETBACKS

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ABSTRACT

Pedagogical projects have often, at KTH Royal Institute of Technology, as well as elsewhere, been initiated and managed by individual enthusiasts rather than dedicated teams. This generally decreases the possibility of successful implementation of more ambitious ideas, e.g., changing educational programs, implementing the CDIO syllabus, or strengthening the pedagogical development of larger parts of the faculty. To enable wider and more effective change, KTH top management therefore launched a university-encompassing three-year project in 2014, in which a group of highly motivated teachers from all schools at KTH were appointed part-time pedagogical developers (PDs). The PDs were given the task of promoting pedagogical development and facilitate cooperation and knowledge exchange among faculty members, as described in two previous papers at CDIO conferences. From 2017, the outcomes of this project are supposed to be integrated parts of the KTH line organization. The project has led to numerous actions, which would have been difficult to set in motion unless given the freedom in time to explore and to develop into a collective effort rather than a myriad of individual “stand-alone” examples. By addressing key areas for pedagogical development, our group of dedicated faculty have tried to surpass the suboptimal "lock-in" of strict individual reasoning and to deal with surfaced questions and relevant issues in a broader collective manner. A major insight confirmed by the project and its many sub-projects has indeed been the fundamental importance of collegial discussions and the creation of processes that facilitate and support teacher cooperation. We have also, through discussions with faculty at KTH, confirmed the need for clearly defined, tangible incentives for teachers, motivating them to participate in pedagogical development activities, even if this means less time left for the traditional pathway to rewards within academia, i.e. research. In this paper, we chart changes that have occurred in the educational practices at KTH by describing and discussing the project’s focus on pedagogical development of faculty, actual execution of changes in the engineering educations, lessons learned along the way, and visions yet to be realised.

KEYWORDS

Pedagogical developers, educational change, change agents, faculty development, CDIO standards.
INTRODUCTION

As stated in CDIO Standard 10 (2010), faculty members need to get proper support and training in order to be able to successfully introduce new types of active, experiential or integrated learning activities in their courses. Reaching such a goal is a university-wide change process which involves almost all faculty members. However, change processes are hard to both manage and execute. There are several models emphasized in the change management literature, and after learning that the majority of extensive change efforts fail, Kotter (1995) couched his model as a way of avoiding major errors in the change process. Todnem By (2005) puts attention on the contradictory advices provided from change management literature overall and that a strong reason to this is due to the lack of empirical evidence. Kotter viewed change management as several key phases to provide guidance, minimize critical mistakes in any of the phases and noted that failure to any of the phases can have devastating impact on the momentum.

Past studies have shown that a few key components to successful change processes are a combination of top-down and bottom-up strategies (Elton 2003, Graham 2012) and a close relation to the day-to-day work performed by individual teachers (Kleijnen et al. 2014). An alternative approach to systematic faculty development is through institutional programs using peer-to-peer support and training of individual teachers e.g. the Carl Wieman Science Education Initiative (Wieman et al. 2010). With a growing academic interest to document and track educational change efforts from a descriptive character (e.g. Kezar and Eckel, 2002; Kolmos and De Graaff, 2007; Reidsema et al., 2013), we attempt to share experiences to benefit both operational and strategic values.

The originating work by Kotter and Schlesinger (1979) and Kotter’s (1995) model can be described as aimed at the strategic level of the change management process. In contrast to this, Jick (1991) developed a model more focused on the tactical level in order to guide the implementation of major organisational change. Jick emphasizes that implementing change is an ongoing process of discovery, and therefore thoughtful questions has to be asked throughout the entire process. Mento et al. (2002) continued to explore the importance of change implementation as a 12-step framework for change made tracking progression a way to fine tune change efforts. The first seven steps of their framework are all relevant to discuss when it comes to the change project that this paper is focusing on. The first (1) step is to identify the idea and its context, the second (2) step is to define the change initiative while the third (3) step is to evaluate the climate for change. After that comes the fourth (4) step that is focused on developing a change plan and the fifth step (5) which is aimed at finding a sponsor. Step six (6) emphasizes that you have to prepare your target audience and step seven (7) states that you have to create a cultural fit in order to make the change last.

In 2014, KTH started the pedagogical developers (PD) initiative, a 3 million Euro project to support the bottom-up part of the change process. This project started from the ground level, i.e. from student perception of their learning environment and everyday problems for teachers (Berglund et al. 2015). In the second year of the project, the PDs developed educational support material for teachers and strengthened the collegial dialogue (Berglund et al. 2016). In this paper, encompassing insights from the third consecutive year, we describe what has been achieved so far, and our change visions for the future. Finally, we draw a set of general conclusions based on the whole PD project, highlighting our approach, the implementations, and efforts to sustain the process beyond the formal project’s end date. Our ambition is to inspire those that are stuck to break loose, or in other words, to find
progression and build momentum towards accepting change as something much needed also in an academic environment.

SHORT SUMMARY OF THE THIRD YEAR ACTIVITIES

During the third year of the project, there has been a continued work on refining the Learning Experience Questionnaire (LEQ) process which is used to obtain information about how students perceive their learning environment (Berglund et al. 2015), and to improve the pedagogical workshops for enhancing the pedagogical skills of faculty members (Berglund et al. 2016). The focus in the LEQ process development has been to make the process more user friendly and the results from LEQ are now automatically imported into a template for course analysis. Systematic work to improve the quality of the workshops has been performed, based on the analyses of written feedback from participating faculty members.

In early 2016, it was decided within the PD group that the main focus of the common activities during 2016 should be to find ways to incorporate the gained experiences at both university and school levels. This work was summarized in a written report to the KTH educational board, where the PDs put forward a list of proposals for future decisions, to promote pedagogical development. A selection of some important issues that the PDs worked with during the third year of the project is presented below.

The PDs:

- made a proposal for improving the process to start new courses.
- made a proposal for the structure of a common document for course information to students.
- suggested a common certificate for global competence.
- participated in the development and testing of new pedagogic courses.
- developed a course for implementing course development in existing courses which utilize many of the outcomes of the PD project.
- acted as a consultation body for input in different pedagogical development projects, e.g. the specification of a new learning management system, and the redesign of lecture halls and classrooms.

The project should be incorporated within the line organization from beginning of 2017. When writing this, we cannot fully grasp the consequences of this organisational change, but 7 out of 10 schools at KTH will at least in the short run continue with PDs in some way, and a small budget for collaborative efforts among PDs have been decided upon. We also note that KTH top management has started an organized university-encompassing dialogue about educational strategies, and that some of the PDs have been assigned to leadership positions in the educational organization.

OUTCOMES FROM A CDIO PERSPECTIVE

It was realized at an early stage that the PD activities could be mapped to CDIO standards and syllabuses (Berglund et al, 2015). This paper takes a deeper look at what has actually been achieved at the end of the three-year project. Table 1 summarizes some of the main activities mapped to relating CDIO standards. We have indicated the outcome/impact
reached by the overall project from an estimate of how well each activity is included in the present educational structure at KTH.

Table 1. The third year PD activity overview and CDIO mapping

<table>
<thead>
<tr>
<th>CDIO Standard</th>
<th>What has been Implemented</th>
<th>Outcome/impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Learning outcomes</td>
<td>Intercultural competence</td>
<td>Certificate of Global Competence.</td>
</tr>
<tr>
<td></td>
<td>Progression in report writing</td>
<td>Implemented at two schools.</td>
</tr>
<tr>
<td>3. Integrated curriculum</td>
<td>Program oriented teacher teams</td>
<td>Created in some study programs.</td>
</tr>
<tr>
<td></td>
<td>Sustainable development</td>
<td>Integrated in most study programs.</td>
</tr>
<tr>
<td>5. Design-implement experiences</td>
<td>Challenge-driven education</td>
<td>Agreements set up for one program.</td>
</tr>
<tr>
<td>8. Active learning</td>
<td>Clickers and similar tools</td>
<td>Used by many teachers (&gt;10%).</td>
</tr>
<tr>
<td></td>
<td>Toolbox for formative feedback</td>
<td>Available online.</td>
</tr>
<tr>
<td></td>
<td>Flipped classroom</td>
<td>Two courses developed by PDs.</td>
</tr>
<tr>
<td></td>
<td>E-learning</td>
<td>Testing and implementation of digital tools.</td>
</tr>
<tr>
<td></td>
<td>Research in education</td>
<td>&gt;10 scientific publications by PDs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 8 scientific publications inspired by PDs</td>
</tr>
<tr>
<td>10. Enhancement of faculty teaching competence: Workshops/Seminars</td>
<td>Assessment methods</td>
<td>Given 4 times, 60 participants</td>
</tr>
<tr>
<td></td>
<td>Designing courses for motivation</td>
<td>Given 6 times, 115 participants</td>
</tr>
<tr>
<td></td>
<td>Educational development with LEQ</td>
<td>Given 3 times, 90 participants</td>
</tr>
<tr>
<td></td>
<td>Flipped classroom</td>
<td>Given 4 times, 60 participants</td>
</tr>
<tr>
<td></td>
<td>Formative feedback</td>
<td>Given 6 times, 135 participants</td>
</tr>
<tr>
<td></td>
<td>Get started with E-learning</td>
<td>Given 2 times, 35 participants</td>
</tr>
<tr>
<td></td>
<td>Help your students to study in your course ILOs and the Course Syllabus</td>
<td>Given 2 times, 25 participants</td>
</tr>
<tr>
<td></td>
<td>Independent students</td>
<td>Given 5 times, 60 participants</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Given 2 times, 20 participants</td>
</tr>
<tr>
<td>10. Enhancement of faculty teaching competence: Other</td>
<td>Communities of Practice (CoP)</td>
<td>&gt;15 lasting ones have been established.</td>
</tr>
<tr>
<td></td>
<td>Classroom observations</td>
<td>Implemented in two CoPs.</td>
</tr>
<tr>
<td></td>
<td>Pedagogical courses</td>
<td>Two new courses have been developed.</td>
</tr>
<tr>
<td></td>
<td>Learning Experience Questionnaires (LEQ)</td>
<td>&gt;400 courses/year.</td>
</tr>
<tr>
<td></td>
<td>Revision of examination methods</td>
<td>Done in one study program.</td>
</tr>
</tbody>
</table>
We now turn to a more detailed description of the PD activities mentioned in Table 1.

**CDIO Standard 2 - Learning Outcomes**

*Intercultural competence:* A university-wide add-on program, ‘Certificate of Global Competence’ has been developed. While technically not part of any study program, and thus seemingly at odds with CDIO thinking, this promises to be a way of making room for learning outcomes seen as important in all programs, and supporting international student mobility, without having to alter these programs’ often painfully worked out syllabi.

*Progression in report writing:* At two schools, PDs have developed progression schemes in report writing. Students get a first-year introduction to academic writing and improve their skills during years 1-3 with increasing demands, followed by a B.Sc. thesis report using the same format and grading as the M.Sc. thesis report (but with less strict requirements).

**CDIO Standard 3 - Integrated Curriculum**

*Program oriented teacher teams:* In a few study programs, PDs have initiated and formed teachers’ teams for the whole program. This all-encompassing approach facilitates the development of an integrated curriculum. Other PDs have worked together with leaders of study programs to initiate program discussions about progression.

*Sustainable development:* Thanks to many different efforts at KTH: the PD project; KTH sustainability office, and different program directors, sustainable development is now implemented in most educational programs at KTH and is being assessed on a university level, since KTH nowadays is ISO certified.

**CDIO Standard 5 - Design-implement experiences**

*Challenge-driven education:* One PD has been working on setting up international agreements for challenge-driven projects, allowing students from different universities to participate in large common engineering projects.

**CDIO Standard 8 - Active Learning**

*Clickers and similar tools:* Many PDs and other teachers have tested and are now using clickers or web-based response systems in education. This development has been strengthened during the last three years and the methodology is starting to become generally accepted among faculty. As an example, one department has purchased 300 clickers to be used during lectures in large basic courses, reaching around 1200 students per year.
Toolbox for formative feedback: The PDs have developed a website that maps a variety of courses and different forms of formative feedback provided by KTH faculty. It is based on interviews and highlights pros and cons experienced, from the teachers’ perspectives.

Flipped classroom: Two PDs have been involved in the development of courses using the flipped classroom pedagogical model. The new engineering program Industrial Technology and Sustainability has an explicit pedagogical foundation focused on flipped classroom with video recorded lectures, gamification and real world problems from industry partners.

E-learning: Most PDs have been involved in testing and evaluating various kinds of digital tools in education. This includes different ways of using video in education, tests of new software for E-learning, making MOOC courses etc. At one department, several second cycle courses use recorded lectures as a significant part of the students’ learning activities, enabling a shift from lectures to seminars with enhanced discussions.

CDIO Standard 9 - Enhancement of Faculty Competence

Equality and diversity: One PD has worked with equality issues when teaching architecture and the small number of female role models put forward within the field. Teacher discussions have been initiated and the results have been put together into rules about equality and diversity.

Research in education: The PDs have published their findings at pedagogies conferences and in pedagogical journals and we can count to more than ten publications so far (most PDs had no publications in the field of pedagogy before the project). Another effect is that the PDs have inspired other faculty members to submit pedagogical innovations as papers to local and international conferences and journals. Deeper studies in areas relevant for advancing engineering education has also been initiated, e.g. understanding students’ study strategies, investigating student motivation driving forces, and testing new ways to introduce peer review to engineering students.

CDIO Standard 10 - Enhancement of Faculty Teaching Competence

Workshops: Nine different workshops for continued education of faculty teaching first and second cycle courses have been developed by the PD group. These workshops have been given on 34 different occasions, with a total of 600 participants. Three of the workshops were given in an international context at Trinity College Dublin, Ireland, and one at the CDIO European Regional Meeting, in January 2017.

Communities of practice: One aim of the PD project was to create new communities of practice (CoP), (Wenger, 2015), where teachers actually talk about pedagogical issues. Every PD has tested a number of different CoPs during their work and every PD have on average introduced one CoP that is foreseen to be continued in the future. The created CoPs are of many different kinds, like e.g. LEQ discussion groups, pedagogical lunch meetings, teachers in mathematics, teacher teams in various study programs, examiner meetings, group of teachers interested in active learning etc.

Classroom observation: As a means to promote reflection and peer exchange, classroom peer observation visits were organised at two school for teachers visiting each other in small groups, following a routine with meetings before and after each visit, discussing first the
focus of each visit and each teacher’s special interest, and after the visits reviewing observations related to these, as well as topics emerging during the visits.

Pedagogical courses: The PDs have developed two pedagogical courses on issues that are seldom covered by courses given by the teaching and learning department:

- **Reflective teaching in a subject perspective** - a course that is run locally at departments to promote community of practice building among teachers.
- **Pedagogical development of an existing course** was developed to enroll teachers that want to make changes in their courses, but need support while doing it.

**CDIO Standard 11 - Learning Assessment**

*Master thesis course:* A thorough revision of a Master thesis course was made to practically include both stakeholder and faculty perspectives and to map goals and assessment methods to program learning outcomes. For example, the course now requires students to write and follow project plans and to make opposition on master theses.

*Learning Experience Questionnaire (LEQ):* A method to assess the students’ learning environments was developed during the project and is based on a questionnaire and a follow-up collegial analysis of courses (Berglund et al 2015). The collegial discussion is included to promote course development by sharing the experience of the participating teachers. In a few courses, students have also been involved in the course analysis process with quite interesting results (they better understand the development process and why it takes time). Although the usage of the LEQ process is not a requirement at KTH, it is spread to all KTH schools and is used by most departments at KTH. During its first year of implementation (May 2015 - April 2016) more than 400 courses were analysed using the LEQ process.

*Revision of examination methods:* In one study program, the PD worked with a thorough revision of all examination methods used during the first year of studies, which also included the work to set up a community of practice with all involved teachers.

**CDIO Standard 12 - Program Evaluation**

Program evaluation projects have been done for many programs at KTH. These projects have often been carried out in response to program evaluations made by the Swedish Higher Education Authority. However, in recent years, more specific program evaluation projects have also started, in order to enhance various aspects of programs. Below, we give a few examples where PDs have been heavily involved.

*Progression analysis of CDIO skills:* When working in close collaboration with study program directors, the PDs have in some cases been asked to make program analyses of specific CDIO skills. The learning objectives and progression of sustainable development skills have been systematically evaluated in one program and discussed in other programs. In another program, one PD has worked with progression of student activities related to innovation management and teamwork.

*First year mathematics - bridging the gap:* There is a gap between what students actually know about mathematics from high school and what they are expected to know when entering university. In two study programs, this gap was investigated by an analysis of
examination results and student enquiries. Based on this analysis and thorough teacher discussions, changes were introduced in the first year curriculum design. A strategic plan for monitoring this gap in the future was also developed.

**Student feedback for program analysis:** In one study program, all students write about and discuss their courses with peers and faculty members, including program management, as part of a meta-course. This data is now systematically collected and analyzed, and used for feedback, both on the program and on a course level.

**DISCUSSION**

Change management theories available to academics and practitioners are often contradictory. From organisational change management literature, e.g. Jick (1991), Kotter (1995) and Todnem By (2005) stress that the lack of empirical evidence and critical screening of efforts made is why implementation successes tend to deviate significantly. The PD project has addressed a large number of issues related to the CDIO syllabus and also been able to create real pedagogical change for individual courses and teachers. From the mapping to the CDIO standards, we can see that a large amount of work has been devoted to faculty development, curriculum improvement and active learning (the latter often related to the introduction of digital tools). On the other hand, efforts have not been put on the CDIO context and on the introduction of engineering to students (CDIO standards 1 and 4 respectively), mainly because these standards are already quite well developed at KTH. The PDs have not focused on CDIO standard 6 about engineering workspaces, since this is an issue for other projects already active at KTH. Finally, no activities are directly mapped to CDIO standard 7, about integrated learning experiences, which is somewhat misleading since many PD activities have in fact been related to work with complementary skills. Hence, the efforts made within the project have quite well reflected the most urgent needs for KTH to develop further within the CDIO concept. It is interesting to notice that this development has emerged and self-organized from a bottom-up approach while still following the first three change steps that Mento et al. (2002) describe. Also the second step enhanced by Mento et al. (2002) that emphasizes the need for defining the change initiative from the start was done through the analysis of the organisation and its need for change. This was performed before the PD project was initiated.

The project can retrospectively be viewed as having followed a three year development process, with the following major activities during the different years:

- **Year 1:** Obtain a basic understanding of how the students perceive their learning environment, and identify the faculty’s needs for pedagogical development.
- **Year 2:** Develop support structures to facilitate and simplify the pedagogical development of the faculty to ensure that change is implemented in a time-efficient manner.
- **Year 3:** Develop and suggest processes to make these activities consistent with the overall university strategy for pedagogical development, and to integrate them in the line organization.

Considering results and experiences gained within the project, we can now start to analyze it from a faculty change perspective. As shown, the PDs have set in motion a number of change processes. The importance of supporting faculty with new pedagogical methods involves what scholars (e.g. Kleijnen et al., 2014, Reidsema et al., 2013, Graham, 2012) address as a way to anchor changes at the level of individual teachers. This has been a
particularly strong point within the PD project, where motivated PDs from the faculty have worked together with engaged teachers to actually create local change.

When organizations meet challenges not previously considered, it is hard to move away from existing practices. From the perspective of path dependency (Wilsford, 1994), this is a situations where structural forces are dominant, and changes are considered an upset to normal traditions. Hence, a strong internal momentum is needed to go beyond the existing path of practices and create a new trajectory. From a change perspective, the PDs have broken some of the internal silos by facilitating sharing of experience between faculty concerning, e.g., new pedagogical methods. This systematic shift can be seen as both a way to prepare the target audience (step 6 in Mento et al’s 2002 framework) as well as a way to create a cultural fit (make the change last), which is step 7. However, there is an obvious risk of losing momentum when - as happened in 2017 – when the financing and ownership of the PD project was moved from central university level to local school level. The anchoring process remains a key ingredient if vital insights are not to be lost in the implementation process. In consequence, this step became a critical setback that stem from a lag within the line organisation when it comes to internal dialogue and decision-making.

The PD activities at different schools have been organized and executed in different ways. Some PDs have been given a large degree of freedom, while others have been more controlled. This aspect might have influenced the motivation and enthusiasm for individual change initiatives for the PDs. Looking at the activity in the PDs’ community of practice, it seems that those PDs with more freedom participated and performed to a greater extent. So, for the continuation of the project, we believe that it is important that the engaged faculty should be given enough freedom to explore their own ideas of pedagogical change. And in the same way that some of the PDs were given a large degree of freedom in what to do, this freedom also needs to be given to the teachers that in future will embark on a similar pedagogical journey that the PDs have undertaken. Allowing for a large degree of freedom is important since pedagogical change is something highly personal for a teacher.

CONCLUSIONS

The PD group have benefitted a lot from the internal discussion within the group. From this experience, it is suggested that organisational structures to support the networking of teachers are needed to implement change on a university-wide level. This way, teachers are given the opportunity to actively discuss pedagogical issues with peers and, thereby, push the pedagogical development. Strategies to work together as an entity during the change process seem to be one of the keys in creating sustainable changes. Another key is to find new and innovative ideas to be able to work efficiently and reduce the workload of individual teachers. Establishing a team work feeling is crucial for the establishment for changing existing courses, programs or similar.

Finally, we shortly recognize a few of the systematic shifts that have occurred during the PD project together. We do this by also portraying a few serendipities discovered during our change path, as well as some noticed setbacks.
**Systematic shifts**

Even though the project just has ended, we can see some systematic shifts that likely will prevail. The first is the use of the LEQ process including the collegial course analysis for sharing experience. Most of the participating teachers express a positive attitude towards sharing their experience with peers. Furthermore, the PDs have been influential in the changes implemented in pedagogical courses and workshops based on teacher needs. The PDs have created and lead faculty dialogues which have resulted in real change as well as have become a vehicle for spreading new pedagogical methods.

**Serendipities**

The main serendipity was arguably the strength found in communities of practices across school and disciplinary divides. The creation of these communities clearly tapped into an unknown need among pedagogically interested teachers. Without it, the efforts would most likely have been much weaker and the results of the project would not likely have reached as far. An additional explanation for the success of these communities was likely the high degree of freedom that was given to some of the PDs, something which in turn was not as much a planned thing as an effect of the line organisation not really knowing what to do with the centrally funded PDs. Together with the open atmosphere in the PD group, the enthusiasm and motivation gave rise to many unexpected ideas. Among these ideas were the topics of the workshops, some of which were developed out of pure interest among the PDs.

**Setbacks**

An important, and possibly fatal, setback in the project has been that we have lost some momentum during the integration of the PD project at school level. More attention should have been given to establishing the outcomes of the PD project in the line organisation already at an earlier stage. The reason for this is not completely clear to us, but one may speculate that the necessity for change had not been sufficiently articulated from the beginning. The necessity to keep the process running has been understood by the top management, who has started up a university-wide strategic dialogue on educational issues, but by the time this has landed in the organisation, no one can know what will be left of the structures and communities formed during the PD project.

**FUTURE CROSSROADS AND CHALLENGES**

Midway through the final year of the PD project, the final report was drafted by the PDs. The reason for filing the report before the project ended was to allow time for KTH top management to make strategic decisions based on the findings from the PD project while the PDs were still involved in the project. Two main future scenarios were identified by the PDs. Firstly, the PDs could support the line organization with issues related to pedagogical development and quality assurance of education. Secondly, the PDs could be part of an organizational structure for spreading good ideas and practice-related research within the faculty and thereby drive the collegial discussions. This means that the PD activity should change focus from developing activities that support pedagogical change to actually reach and inspire a large part of the faculty to implement change. Accordingly, it was suggested that the PD project should be reformulated into a new organizational structure with both a School specific part and a common part to support this development. In this way, KTH can
build up a university encompassing pedagogical network with the ability and the competence to actually implement change. To simplify the change process, the PDs suggested to KTH top management a number of administrative interventions that needed to be in place.

Most importantly, it is suggested that a development-oriented university-wide pedagogical program is created with a focus to support teachers to actually perform pedagogical development. As part of such a program, it is suggested that each School at KTH should have a pedagogical council working with quality issues related to pedagogics. In addition, a decision should be taken that course evaluations and course analyses should follow the Standards and Guidelines for Quality Assurance in the European Higher Education Area (ESG). It is also suggested that every course should have a course description which includes the teacher’s pedagogical view on the course. Finally, at a program level, it is suggested that a method for collegial program development and assessment, similar to the one developed for collegial course development, should be developed.

Organisational decisions are, however, not sufficient to implement change - support structures for teachers are also needed. Hence, it is suggested that course analysis should be done in a collegial setting (on scheduled meetings) where experiences could be shared among teachers. To promote a pedagogical discussion across school boarders, it is suggested that a forum where interested teachers can meet and discuss pedagogical issues is created. To give appraisal to pedagogic work, it is suggested that a pedagogical academy should be established, faculty should be encouraged to document and publish pedagogical development and research work and an “Educational Environment of the Year” prize should be inaugurated. At an individual level, each teacher should have a pedagogical development plan with clear and measurable goals to enable KTH to appraise pedagogical efforts.

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**BIOGRAPHICAL INFORMATION**

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MAPPING THE CDIO CURRICULUM WITH NETWORK MODELS

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Department of Aeronautics and Astronautics
Massachusetts Institute of Technology

ABSTRACT

This paper describes the creation of a mathematical model that represents the mapping of an undergraduate engineering degree program to the CDIO syllabus. A network model represents entities as nodes and relationships among entities as links between nodes. In the CDIO curriculum mapping network model, CDIO skills and program courses are modeled as entities. The network model defines directed relationships to represent the mapping between courses and CDIO skills. A relationship exists if a course addresses a CDIO skill. The result is a structured model on which we build scalable educational analytics and data visualization tools. The approach is demonstrated for the MIT undergraduate program in Aerospace Engineering.

KEYWORDS

Curriculum Mapping, Educational Analytics, Interactive Data Visualization, Standards: 1, 2, 3, 11, 12

INTRODUCTION

The CDIO (Conceive – Design – Implement – Operate) engineering education model provides a benchmark for assessing how a curriculum satisfies standards outlined in the CDIO syllabus (Bankel et al., 2005). The CDIO Initiative was conceived and developed in 2000 through a collaboration among the Massachusetts Institute of Technology (MIT), Chalmers University of Technology, Linköping University, and KTH Royal Institute of Technology, with financial support from the Wallenberg Foundation (Crawley et al., 2011). Since then, the CDIO framework has been adopted by engineering programs worldwide, playing a key role in curriculum design, teaching and learning, assessment and evaluation (Crawley et al., 2008).

The mapping of CDIO skills to courses within a curriculum is a core activity in the CDIO model that promotes discussion and analysis. Such a mapping is essential to support a gap analysis, to ensuring that skills are not applied before they are taught, and to balancing skill coverage across courses (Loyer et al., 2011, Crawley et al., 2014). To date, mapping is done by collecting tables of courses, program outcomes or other program attributes and corresponding CDIO skills (for examples, see Brennan et al., 2010, Campbell et al., 2009,
Cloutier et al., 2010, Gunnarsson et al., 2007, Loyer et al., 2011). Table 1 is an example of such a table.

Table 1. Example of a typical mapping in table form of courses in a curriculum to CDIO skills

<table>
<thead>
<tr>
<th>CDIO Skill</th>
<th>Course</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1.1 Problem Identification and Formulation</td>
<td>Course A, Course B, Course F</td>
</tr>
<tr>
<td>2.2.2 Modeling</td>
<td>Course B</td>
</tr>
</tbody>
</table>

With only a table format, it is often difficult to conduct inference and pathway analyses. For example, a table does not easily reveal in what order skills are introduced, taught and applied throughout the program. It is also difficult to gain a holistic sense of a program’s topology with respect to CDIO coverage, answering questions such as: what is the distribution of skill coverage across courses? Because CDIO skills are cross-curricular and crosscut disciplines (Crawley et al., 2014), it is potentially useful to visualize an entire program’s mapping to CDIO skills, beyond the table-based views of traditional spreadsheets.

In this paper, we introduce a mathematical network model that represents the mapping of a program to the CDIO syllabus. We apply our model to the MIT Aerospace Engineering program, mapping courses in the program to the CDIO syllabus. We show that the resulting network-based structure supports scalable visualization and analytics.

CDIO CURRICULUM MAPPING MODEL

In this section we formulate a network model for representing an educational program and its mapping to the CDIO syllabus. The two key elements of a network model are nodes and edges. A network structure represents entities as nodes and relationships between entities as edges between nodes.

In our CDIO curriculum mapping network model, we define four different types of entities:

- **content**: entities of type `content` represent a curricular unit of interest. This is often a course in curriculum design and accreditation processes; however, other curricular entities can be chosen as well, for example, learning units, resources, modules, etc.
- **CDIO skill**: these entities represent the elements of the CDIO syllabus. Here we use CDIO Syllabus v2.0.
- **group**: these entities represent units of organization in the curriculum. For example, courses may be grouped according to the type of course (elective, core, capstone, etc.). We may wish also to group the CDIO skills in clusters.
- **program**: these entities represent the programs being modeled.

Each entity is represented as a node in the network model. Information on the entity is modeled as a property of the node. The type of entity is one piece of information. For courses, we may include other properties such as the website URL of the course, the number of credits the course is worth, etc.

In our CDIO curriculum mapping network model, we define two different types of relationships:
addresses: this is a directed relationship used to indicate that a course addresses a CDIO skill. If Content A addresses CDIO skill 2.1.1, we create a directed edge between the node of Content A and the node of CDIO skill 2.1.1 (Figure 1). The addresses edges are assigned a weighting to indicate how strongly a course addresses an outcome.

Figure 1. Content A addresses Skill 2.1.1

has-parent-of: this is a directed relationship that specifies organizational hierarchy. We use these relationships to relate courses to a group, and groups to a program. We create a directed edge of has-parent-of type from Content A to Group X, if Content A belongs to Group X (Figure 2).

Figure 2. Content A has the parent of Group X, i.e., it belongs in Group X

Modeling the program in this way gives us a structured foundation for visualization and analytics. In particular, we can now apply to our network model the powerful tools of graph visualization and graph analytics to reveal insight into program structure and to analyze how the program maps to the CDIO syllabus. The next section shows this in detail for a case study of an undergraduate aerospace engineering degree program.

MAPPING A CDIO-BASED AEROSPACE ENGINEERING PROGRAM

In this section we model the MIT undergraduate degree program in Aerospace Engineering and its mapping to the CDIO syllabus. We demonstrate visualization and analytics using the network model.

In this example, we model the degree program at the level of individual courses – our content nodes are undergraduate courses taught in the Department of Aeronautics and Astronautics at MIT1. The first step in creating the network model is to identify all the entities. In the model we have 20 courses, 87 CDIO skills, 17 groups, and 1 program. Each one of these entities is a node in the network model.

The second step in creating the network model is to identify all the relationships. In this case we identify 124 has-parent-of relationships that specify organizational groupings. We define a parent group for each course in the categories “Aerospace Engineering Core,” “Aerospace

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1 Note that the Aerospace Engineering curriculum includes courses taught by other departments (mathematics, physics, chemistry, biology, computer science, humanities, arts and social sciences). Those courses are not included in the CDIO mapping presented here.
Engineering Capstone” or “Aerospace Engineering Elective.” Similarly, we use has-parent-of relationships to group the CDIO skills into their 14 categories (“2.1 Analytical Reasoning and Problem Solving” etc.). Each of the 17 groups also has a has-parent-of relationship that links it to the overall program.

We then define 516 addresses relationships that map each individual course to the set of CDIO skills. These mappings were created using data collected from faculty members during the end-of-semester course reflective memo process. Each faculty member is asked to specify which of the CDIO skills they introduce, teach and apply in their course. Table 2 shows a sample of the raw data collected from the faculty member teaching course 16.90 Computational Methods in Aerospace Engineering. Table 3 summarizes the features of the overall mapped data set, including the attributes that are assigned to each entity and relationship. The network model has in total 125 entities and 640 relationships.

Table 2. A sample of the raw data mapping course 16.90 Computational Methods in Aerospace Engineering to the CDIO skills.

<table>
<thead>
<tr>
<th>2.1 Analytical Reasoning and Problem Solving</th>
<th>I</th>
<th>T</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1.1 Problem Identification and Formulation</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1.2 Modeling</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1.3 Estimation and Qualitative Analysis</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1.4 Analysis with Uncertainty</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.1.5 Solution and Recommendation</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.2 Experimentation, Investigation, and Knowledge Discovery</td>
<td>I</td>
<td>T</td>
<td>A</td>
</tr>
<tr>
<td>2.2.1 Hypothesis Formulation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.2.2 Survey of Print and Electronic Literature</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.2.3 Experimental Inquiry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.2.4 Hypothesis Test and Defense</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Summary of mapped MIT aerospace engineering CDIO curriculum

<table>
<thead>
<tr>
<th>Entities</th>
<th>Count</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content</td>
<td>20</td>
<td>URL, Keywords</td>
</tr>
<tr>
<td>CDIO skill</td>
<td>87</td>
<td></td>
</tr>
<tr>
<td>Group</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Program</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relationships</td>
<td>Count</td>
<td>Attributes</td>
</tr>
<tr>
<td>has-parent-of</td>
<td>124</td>
<td></td>
</tr>
<tr>
<td>addresses</td>
<td>516</td>
<td>Introduce/Teach/Apply category</td>
</tr>
</tbody>
</table>

Figure 3 is a visualization of the mapped dataset. CDIO skills are visualized as small red nodes, grouped into their categories. Courses are visualized as larger nodes, grouped as Core, Capstone and Elective. The visualization is interactive and accessible online at mapping.mit.edu/cdio-mapping. To create this visualization, the authors used the online
Rhumbl visualization tool\(^2\); an example of the spreadsheet used to create the visualization is also available at mapping.mit.edu/cdio-mapping for download, and can be used as a template for other researchers who wish to create visualizations of their own CDIO data.

Figure 4 shows a snapshot of the interactivity displaying the CDIO skills that are addressed by the selected course (here 16.06 Principles of Automatic Control).

Figure 5 shows a snapshot of the selected CDIO skill of The Design Process Phasing and Approaches (4.4.2) and the courses that address it: Unified Engineering Fluid Dynamics (16.003), Unified Engineering Thermodynamics (16.004), Structural Mechanics (16.20), Real-Time Systems & Software (16.35), Autonomy (16.410), Experimental Projects (16.62x), Flight Vehicle Development / Engineering (16.82x) and Space Systems Development / Engineering (16.83x).

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\(^2\) Rhumbl (rhumbl.com) is a free online visualization tool that lets users create interactive network visualizations from spreadsheets. It was created by the authors in 2015.
This network model provides a basis on which to conduct analysis of the program and its mapping to the CDIO syllabus. For each CDIO skill we can analyze its coverage in the program. The indegree of a node in the network model is a count of the number of incoming
edges, while the outdegree of a node is a count of the number of outgoing edges. Thus, the indegree of a CDIO skill node specifies the number of courses that address that skill. Similarly, the outdegree for addresses relationships of a course node specifies the number of CDIO skills addressed by that course. In both cases, we could also use the attribute of Introduce/Teach/Apply to break down these counts into their ITA categories.

Figure 6, Figure 7, Figure 8, show the indegree calculations for the MIT aerospace engineering data set. As expected, the courses map strongly to the skills of Analytical Reasoning and Problem Solving (2.1), as well as skill Critical Thinking (2.4.4). The program courses also have a strong coverage of Teamwork (3.1), Communications (3.2), Conceiving, Systems Engineering, and Management (4.3), and Designing (4.4). We note that while the plots show some CDIO skills with no coverage in the mapped courses, MIT students likely receive exposure to these other skills in their other required courses outside the department.

In general, this kind of analysis will reveal areas of strength and potential gaps of coverage in a curriculum. This analysis is also useful in considering the effects of curriculum redesign on coverage of the CDIO syllabus. Noting that students select only a subset of courses, these scores could also be combined with student enrollment data to analyze student exposure to the CDIO syllabus, either for an individual student or in aggregate across the student population.
Figure 6. The indegree of CDIO skill nodes (here categories 2.1 through 2.5) specifies the number of aerospace engineering courses that address each skill.

Figure 7. The indegree of CDIO skill nodes (here categories 3.1 and 3.2) specifies the number of aerospace engineering courses that address each skill.
Figure 8. The indegree of CDIO skill nodes (here categories 4.1 through 4.7) specifies the number of aerospace engineering courses that address each skill.
An outdegree analysis of the courses shows that the capstone courses address more CDIO skills than any of the other courses in the program. This result is consistent with the design of the aerospace engineering curriculum, which strongly embeds CDIO principles within these capstone courses. We do not present the detailed quantitative results for the course outdegree analysis because of the possible noise introduced by having each course mapping done by a different faculty member. The data support analysis of general trends, but a detailed numerical comparison between courses is not meaningful with this particular data set.

CONCLUSION

A network model provides a basis on which to analyze and visualize the mapping of an educational program to the CDIO syllabus. In the example presented here, the curriculum was modeled at the level of a course, but the network model has the flexibility to model at any level specified by the modeler. In performing a detailed curriculum gap analysis, it may be desirable to model at a more granular level, such as learning units, modules, course learning outcomes, etc. This paper showed how analysis of node degree provides insight into the relationship between program courses and CDIO skills. With the network model in hand, other graph analysis techniques can also be employed. Path analyses may be of specific interest, particularly if the curriculum model is combined with student data. The visualization can play an important role in sharing the CDIO mapping among instructors and program coordinators (and indeed among different institutions as well). Since often the mapping for each course is done by an individual instructor, interpretations can vary and thus impact the quality of the resulting integrated dataset. Having the data available in a clear, interactive and searchable visualization can greatly facilitate the conversations needed to address this issue.

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CDIO IMPLEMENTATION
A CASE STUDY OF CDIO IMPLEMENTATION IN THE COURSE OF HACKING EXPOSED AT DUY TAN UNIVERSITY

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ABSTRACT

Integration of theoretical knowledge and practical skills in teaching and learning is usually one of the focuses in CDIO implementation. However, it is not always as smooth as it should be for some study subjects. Hacking exposed in Information Technology (IT) is one of such subjects: without the theoretical knowledge about computer networks, it is almost impossible to develop computer hacking skills while learning computer network theories or practices by-the-book only will not yield much benefit when the technology changes. This paper presents a real-world case study for successful learning of the course of Hacking Exposed at Duy Tan University by combining the teaching of an in-school project with the trying-out of at-work practices in attacking and defending computer networks. Specifically, the in-school project is closely structured around related network theories while the at-work practices to be learned at each stage of the project are openly discussed and tried out on various computer platforms and/or with any newly-introduced trick and tip. At-work practices can be learned both at school in computer labs or at companies in the industry which have ties with the university. In addition, CDIO guidelines and criteria for Standard No. 5 and 7 are utilized in the structure of this proposed approach. That way, as much as at-work practices may change in the everyday real world, the structures of the project do not have to change that much as long as related theories still hold their value. If it is no longer necessary to learn a certain theory, instructors may remove that theory and its related at-work practices all together. The validity of this case study is backed by observation the way instructor and students of Hacking exposed class. The results of this study are helpful in leveraging instructors’ flexible handling of the course materials and in enabling students to master both hacking skills and knowledge in a shorter amount of time.

KEYWORDS

CDIO Standard No. 5, 7, Hacking Exposed, practical skills development, project-driven approach

INTRODUCTION

In recent years, industry began to find that graduating engineering students, while technically adept, lacked many skills and abilities required in real world engineering situations (Lynch, Seery, & Gordon, 2007). Traditional teaching methods often failed to achieve the goals set out by industry. The challenge from industry, and increasingly from government, still remains:
to increase the quality of engineering education. It is widely acknowledged that universities must do a better job at preparing engineering students for this future through the reforming engineering education (McMasters, 2004). They seek to enhance the preparation of engineering students through the development of a systematic reform of engineering education, based on adaptations of the Conceive - Design - Implement - Operate (CDIO) approach in teaching programs (Crawley et al., 2007).

CDIO is an innovative initiative, which offers an alternative educational framework for producing better-prepared and highly skilled engineers (Elamvazuthi et al., 2015). This method aims to provide students with an education that stresses engineering fundamentals based on the life cycle of a product (Lynch et al., 2007). The students learn to solve problems and complete projects following the stages: Conceive, Design, Implement, and Operate. CDIO promotes goal orientated, project based learning where the aims and desired learning outcomes are clearly stated prior to the students starting any project or before any instruction is given. It aspires to create challenging experiences in which students design, build and operate product systems.

This teaching method is an open architecture endeavor and is available to all engineering programs to adapt to their specific needs. But the use of CDIO in DUY TAN UNIVERSITY (DTU) is still at an initial stage and needs practical verification. This article illustrates the way to conduct the Hacking Exposed course by leveraging CDIO method for enhancing students’ performance. Standard No. 5 and 7 are utilized in the structure of this proposed approach. The purpose of this study is twofold. First, it aims to investigate the different approaching ways of leveraging CDIO in stimulating learning outcome of Hacking Expose course. Second, this study intends to generalize the effective way to teach IT course by using CDIO. This provides a basis for DTU to promote CDIO, and could promote further research on the use of CDIO. Moreover, this study also provides insights to instructors on how to improve their students’ performance. The remainder of the study is organized as follows: the following section review theoretical background for developing framework and propositions, the next section describes data collection and analysis, and the last sections presents the results and the implications for researchers and practitioners.

THE CDIO APPROACH

CDIO is a teaching model developed from 2000, by four universities, including MIT (Berggren et al., 2003). At present, there are more than 90 well-known universities in the world actively promoting CDIO. It works as an education concept and methodological system to guide the reform of the engineering education training model. It combines conception, design, implementation and the entire operation process as the means for developing students’ engineering ability. By using the product life cycle model students develop a better appreciation for engineering processes and in doing so also develop the skills listed above. Each stage helps develop different skills in the students required by engineers (Lynch et al., 2007).

(1) The Conceive stage involves defining the needs and problems to be solved and technology required, considering the enterprise strategy and regulations.
(2) The Design stage focuses on creating the design the plans, working drawing, and algorithms that describe what will be implemented in completing the project.
(3) The Implement stage involves transforming the design into the product solution. This includes manufacturing, coding, testing and validating.
(4) The Operate stage involves operating the implemented product to deliver the intended function, including maintaining, evolving and retiring the system.

The CDIO initiative has defined twelve standards that any program set up under the CDIO syllabus must meet in order to ensure the highest standard of education is maintained. However, in this study we focus on Standard 5 “Design - Build Experiences” and Standard 7 “Integrated Learning Experiences”. Because we want to illustrate the way in which instructors provide students with the skills of active learning, practice, problem-analysis and problem-solving, and focus on vocational skills training, professional ethics, and teamwork and communication.

**Standard 5 — Design-Implement Experiences**

The term design-implement experience describes a range of engineering activities central to the process of developing new products and systems. Included are all of the activities described at the Design and Implement stages, plus appropriate aspects of conceptual design from the Conceive stage. Students develop product, process, and system building skills, as well as the ability to apply engineering science, in design-implement experiences integrated into the curriculum. Design-implement experiences are structured to promote early success in engineering practice. Iteration of design-implement experiences and increasing levels of design complexity reinforce students' understanding of the product, process, and system development process. They also provide a solid foundation upon which to build deeper conceptual understanding of disciplinary skills (Brodeur & Crawley, 2009).

**Standard 7 — Integrated Learning Experiences**

Integrated learning experiences are pedagogical approaches that foster the learning of disciplinary knowledge simultaneously with personal and interpersonal skills, and product, process, and system building skills. They incorporate professional engineering issues in contexts where they coexist with disciplinary issues. Industrial partners, alumni, and other key stakeholders are often helpful in providing examples of such exercises. Furthermore, it is important that students recognize engineering faculty as role models of professional engineers, instructing them in disciplinary knowledge, personal and interpersonal skills, and product, process, and system building skills. With integrated learning experiences, faculty can be more effective in helping students apply disciplinary knowledge to engineering practice and better prepare them to meet the demands of the engineering profession (Brodeur & Crawley, 2009).

**RESEARCH FRAMEWORK**

Traditionally engineering modules are taught through the combined use of lectures, tutorials and practical sessions. This structure has many advantages as it provides the students with a cyclical approach to learning (Lynch et al., 2007). This structure can often fail to fully develop the vital problem-solving and project-based skills required in real world engineering projects. However based on Standard 5 and Standard 7 of CDIO approach can easily be integrated into any engineering program. The teachers should create a course plan and good teaching environment. They also make use of the practical training capabilities of applied undergraduate colleges. The practical projects are introduced into the course teaching. Students should master project development and management through the situational
teaching model. This will improve students’ problem-solving and team co-ordination abilities. The project task is carefully designed with respect to:

(1) **C** (Conceive): The project deliverable is unconventional in the sense that students have limited prior experience with similar products. A pioneering situation enhances the conceiving phase and encourages students to engage deeply in the main technical challenges and approaches.

(2) **D** (Design): The task is difficult enough to be a true challenge to students, yet possible to solve if the work is organized and carried out well. One of the main objectives of the course is to encourage students in applying theory, analysis tools, and methodologies learned in other courses, thereby solidifying their knowledge and gaining confidence in their role as engineers.

(3) **I** (Implement): The size and complexity of the product will entail teamwork and coordination, and provide opportunities to obtain practical experience from real manufacturing on a prototype level.

(4) **O** (Operate): The task is formulated in such a way that the assessment of the results involves operation of the product and evaluation of its performance with respect to technical specifications.

In groups, and driven by the project design, under the guidance of teachers students continuously discover and raise questions related to the project, which strengthens their learning. They develop designs, carry out practical tests, identify defects and summarise their design experience to further deepen their knowledge and practical application ability. On the journey to the final project, their skills have been updated and their performance is improved. Based on the above discussion we propose the research framework as follows (Figure 1):

![Figure 1. Proposed research framework](image-url)
HACKING EXPOSED COURSE AT DUY TAN UNIVERSITY

Located in Danang, Duy Tan University (DTU) is the biggest private university in the Central of Vietnam. A majority of the students are from the local province and 80% of those choose a workplace in cities in Central provinces. By leverage CDIO method DTU can provide students with specialized knowledge to meet the needs of economic and social development. Most of courses in DTU have been conducted in the collaborative way to enhance the interaction between teacher and students as well as students and students. The Hacking Exposed (HE) course is a mandatory subject for all final-year undergraduate students enrolling in the Network Security of CMU Program in International School at DTU. The purpose of HE course is not to teach students how to be a hacker, but rather to teach students the approaches used by hackers so students can better defend against them. All students have no experience in this field. However, before finishing this course, they are required to submit 3 projects related to Penetration test (SQL injection). SQL Injection can provide an attacker with unauthorized access to sensitive data including, customer data, personally identifiable information, trade secrets, intellectual property and other sensitive information. SQL Injection can be used in a range of ways to cause serious problems. It is necessary that students pursuit for the course by solving engineering problems.

Students need to work hard to find the way to fulfil the requirements. The teacher requires groups to have between 4 to 6 members. Students first had to come up with or Conceive ideas and solutions to the problem. They then proceeded to Design how to apply theory, analysis tools, and methodologies learned in course to solve problem. At this stage a procedure is produced to assess the success of their design. Once a satisfactory design has been produced, the students then begin to make the execution (Implement), using their combined skills and the strengths. On completing the project the students will proceed to Operate and test their work. This follows the life cycle of any product and provides the students with clearly distinct stages to follow, developing necessary skills along the way.

By leveraging SQL Injection, an attacker could bypass authentication, access, modify and delete data within a database. In some cases, SQL Injection can even be used to execute commands on the operating system, potentially allowing an attacker to escalate to more damaging attacks inside of a network that sits behind a firewall. In this study we focus on three main ways which an attacker can hack a website, the detailed information of each case is given below (Table 1).
**Table 1. Case description**

<table>
<thead>
<tr>
<th>Category</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Topic</strong></td>
<td>Use command line to hack a website</td>
<td>Use Havij SQL Injection Tool to hack a website</td>
<td>use SQL MAP to hack a website</td>
</tr>
<tr>
<td><strong>Project time</strong></td>
<td>7 days</td>
<td>3 days</td>
<td>10 days</td>
</tr>
<tr>
<td><strong>Purpose of case project</strong></td>
<td>Require students understand SQL injection and simple command prompt to hack a website</td>
<td>Require students have ability to leverage existing tool to hack a website</td>
<td>Require students understand more complex command to hack a website and learn a new language (Python)</td>
</tr>
<tr>
<td><strong>Operating system</strong></td>
<td>Window</td>
<td>Window</td>
<td>Linux</td>
</tr>
<tr>
<td><strong>Process to conduct case project</strong></td>
<td>1. Lecturing</td>
<td>Instructor provides vulnerability of SQL and the way to explore SQL injection</td>
<td>Instructor provides more knowledge of Havij SQL Injection Tool</td>
</tr>
<tr>
<td></td>
<td>2. Classroom discussion</td>
<td>Students discuss to explore vulnerability of SQL concepts and to find tool to figure out SQL injection</td>
<td>Students discuss the way to install Havij SQL Injection Tool</td>
</tr>
<tr>
<td></td>
<td>3. Out-of-class research, analysis (Conceive, Design)</td>
<td>Students study command prompt to hack and figure out the procedure to hack a website</td>
<td>Students study how to use Havij and figure out the procedure to hack a website</td>
</tr>
<tr>
<td></td>
<td>4. Case practice (Implement, Operate)</td>
<td>Students find websites and start to hack</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. Submit results</td>
<td>Students submit hacked website with user and password (1 website)</td>
<td>Students submit hacked website with user and password (4 website)</td>
</tr>
<tr>
<td></td>
<td>6. Presentation - discussion</td>
<td>Students present how to do</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. Evaluating</td>
<td>Instructor give comments and evaluate performance</td>
<td></td>
</tr>
<tr>
<td><strong>Linking with industry</strong></td>
<td>Students come up with a report and send to companies which have websites were hacked. In case, the company want to fix problem they can contact with them and make sign a real project.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In case 1, the topic is assigned is “Using command prompt to hack a website”. Students need to understand and follow the following steps to finish their project:
Step 1 - Finding Vulnerable Website: Students find the vulnerable websites by using Google Dork list. The use “inurl:” command for finding the vulnerable websites.

Step 2 - Checking the Vulnerability: Students should check the vulnerability of websites by adding the single quotes (‘) at the end of the url and hit enter.

Step 3 - Finding Number of columns: After finding the vulnerable websites, they need to find the number of columns in the table by replacing the single quotes (‘) with “order by n” statement.

Step 4 - Displaying the Vulnerable columns: Using “union select columns_sequence” Students find the vulnerable part of the table. Replace the “order by n” with this statement and change the ID value to negative

Step 5 - Finding the Table Name: Now they have to find the table name of the database. Replace the n with “group_concat (table_name) and add the “from information_schema.tables where table_schema=database ()”

Step 6 - Finding the Column Name: Then students replace the “group_concat (table_name) with the “group_concat(column_name)”

Step 7 - Finding the Account: Finally, they get the result – a website with user name and password

In case 2, the assigned topic is “Using Havij SQL Injection Tool to hack a website”. Students need to follow the below steps:

Step 1 – Run Havij.exe

Step 2 – Find Database name: Havij will start SQL injection to the target provided URL. It perform queries to analyze IP, web server, PHP version, Database MySQL version. Then, using Insertion type (‘) string, it proceeds to find column count, column string, finally Database name. After it finds out Database name, Status becomes Idle saying “I’m IDLE”.

Step 3 – Find Tables: Havij Pro will fetch all the tables for the selected Database.

Step 4 – Get columns: Tick the table which you finds important regarding your aim and click Get Columns button. This step reveals all the columns in selected table.

Step 5 – Finally, select important columns of a table (for ex., admin) and click “Get Data” button. The result that name, email, password, user ID everything is revealed.
In case 3, the assigned topic is "Using SQL map to attack a website". Students need to follow the below steps:

- **Step 1 - Find a Vulnerable Website**: This is usually the toughest bit and takes longer than any other steps.
- **Step 2 - List DBMS databases using SQLMAP SQL Injection**: Students find SQL Injection vulnerable website and need to list all the databases with vulnerable database.
- **Step 3 - List tables of target database using SQLMAP SQL Injection**: Now they need to know how many tables this SQL dummy website database got and what are their names.
- **Step 4 - List columns on target table of selected database using SQLMAP SQL Injection**
- **Step 5 - List usernames from target columns of target table of selected database using SQLMAP SQL Injection**. However, in this case students cannot find any user or password, since the limited time and experience.
Based on the case study, we found that CDIO-based pedagogy is penetrated into the whole teaching process. Lecture is conducted before executing the classroom discussion, out-of-class research and analysis, case practice, etc. Classroom discussion emphasizes on the inspiration of professional knowledge, its content is characterized by the concept of SQL injection. Teachers are offered a leading role in the class process. Students are required to answer many questions on the concept of SQL injection and its specific details, e.g., why SQL injection should be studied? Which method should be used for hacking a website? How about its specific requirement? How to analyze the application of SQL injection and how about the practical process? What principles should be followed? All these questions facilitate teacher’s seeking for the practical situation of student’s knowledge understanding, and they also prompt student’s thinking in class and prepare for following case discussion.

After the instruction of basic concepts is completed, students are separated into several studying groups; several case questions of teacher and predetermined tasks are discussed and conceived in each group respectively. Students of each group should reach their own consensus and the discussion conclusions are recorded in detail and submitted after the class is finished. Furthermore, a student representative from each study group is requested for stating the basic viewpoints of his group, and debating can take place when other groups have their respective viewpoints. During this process it is teacher’s responsibility that the discussion should be guided correctly and student’s initiative should be fully promoted. This task will be more detailed and complex than the traditional classroom discussion. The analysis of a practical case is a new teaching step and pedagogy method by which the grouped students select an appropriate example for studying and practicing by themselves. With the accumulated knowledge obtained by different projects, the capability of independent analysis is established in students, and through the group discussion and classroom debate the preliminary conception and design of the whole knowledge system of SQL injection are obtained.

REFLECTIONS AND DISCUSSION

Through practical operation students can learn basic concepts of SQL injection. The practice process will lead students to understand different methods to attack a website and preventing solutions. The whole process is characterized by case evaluation and student’s participation, teacher is only regarded as an academic advisor, and he gives a necessary advice only when practical difficulties exist. On the other hand, teacher can also put forward some technical requirements during the building attacking procedure and solution, which makes the projects developed, be more practical and feasible. Different case, teachers figure disadvantages and advantages to help students get un-depth understanding (Table 2).

<table>
<thead>
<tr>
<th>Case</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>Students understand the rules of SQL injection and procedure of hacking a website by using command prompt (step by step)</td>
<td>It takes time to understand technical problems.</td>
</tr>
<tr>
<td>Case 2</td>
<td>It is easy for students to execute this method by using GUI. Student learns a new and efficient technique “Bypass” in SQL”. With diversified hacking methods, students can attack more website</td>
<td>It not Student no need to understand SQL injection well, just use available tool</td>
</tr>
<tr>
<td>Case 3</td>
<td>Students understand the way to use open source, and study new language - Python</td>
<td>It takes time to understand new language</td>
</tr>
</tbody>
</table>
By leveraging the concept of Standard 5 and 7, we found that CDIO-based method serve as vehicles for developing students’ engineering skills while at the same time deepening their understanding of technical knowledge. It is obvious that relevant skills such as Self-learning ability, Problem-solving, Communication, Teamwork, Knowledge acquisition are improved during implementation case project. Although, CDIO method provides effective and motivating design-implement experiences for students, it also makes instructors face some challenges:

- Learning outcomes for design-implement experiences need to distinguish between product performance and learning performance.
- The task of the design-implement experience must be sufficiently complex, yet limited in scope, to ensure successful outcomes for students. Instructors and students sometimes see the achievement of a good technical solution as the real learning outcome. Failure in the task can be perceived as failure in learning.
- Design-implement experiences require teaching and assessment practices that are different from traditional instruction.
- Few instructors are prepared to assume responsibility for technically challenging projects. In a typical engineering department, only a few faculty and staff have personal, practical experience of developing complex systems.

CONCLUSION

Implementing the CDIO model of practical teaching is not complicated, and is an innovative model for engineering and science education within universities. Specifically, it was used to establish a reasonable and complete teaching system in computer major. The basic principles of CDIO are fairly simple, with wide application, and can be adopted for the teaching of most courses. We found that the overall quality of students had been improved significantly and the employment situation was getting better. In the teaching practice, the pedagogy method and learning organization are improved and optimized continuously through extensive assessing and scientific evaluating; finally the goal of fully mobilizing student’s learning initiative and developing his practical ability by CDIO-based teaching theory can be reached.

REFERENCES


**BIOGRAPHICAL INFORMATION**

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INTERNATIONAL INTENSIVE PROJECTS IN ENGINEERING EDUCATION

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ABSTRACT

European universities organized numerous international Intensive Projects (IP) during Erasmus Lifelong Learning Program 2007-2013. The main principle of international IP was to gather students and teachers from partner institutes together for 2-3 weeks long intensive, project-based learning experience. Students were divided into multicultural teams, which solved a topical engineering problem in CDIO Context.

Subject was selected to be multidisciplinary and comprehensive. Students participating on the IP reported that it was an eye-opening experience. This was due to the multi-disciplinary approach where students were forced out of their comfort zones and were required to collaborate with team members. The class schedule was designed such that student groups were required to do conceive phase, design phase, and implementation phase.

For teachers, the IP was deepening long lasting relationships and was providing an opportunity where teachers could freely open discussions on various topics. The IP strengthened the partnership between the universities. In many cases the IP gave a conceiving ideas for curricula or course content enhancements. In the academic world there are rarely, hardly ever, an opportunity to develop new course content with 10 - 20 colleagues in an international context.

This paper introduces the concept, summarizes the results, and proposes how IP’s can be revitalized without external funding.

KEYWORDS

Intensive project, multicultural projects, Project-Based Learning

INTRODUCTION

Metropolia University of Applied Sciences has experience on participating or coordinating Intensive Projects (IP) with European partner universities. Although the IP’s were very successful and they had undoubted benefits for academic co-operation between European universities, the start of new Erasmus+ program in 2014 also same time discontinued
Erasmus IP funding. The IP’s ended, since without short term mobility support the students are not willing to pay extra for 2-3 weeks long study period abroad.

The main principle of international IP was to gather students and teachers from partner institutes together - each year in different location - for 2-3 weeks long intensive, project-based learning experiment (Piironen, 2012). Students were divided into 3-5 student multicultural teams, which solved a topical engineering problem as a Design-Implement Experience (CDIO Standard 5). At the end of the IP, student's projects were evaluated, and received credits were acknowledged as a part of degree studies at their home institute. Same partner networks organized typically three rounds of similar intensive projects with different topics. Also it is important to notice that many of the students had not participated in team work using a foreign language before (Kitsnik et al., 2003).

Self-evaluation was an integrated part of the IP. All students and teachers had to participate at least the end evaluation. Some IP’s used also intermediate checkpoints to ensure proper workflow during the IP. The analysis results of evaluations were used to improve the concept for the next round of the IP.

Overall, the results from the IP’s were exceptional. The aims and objectives were well achieved. International multicultural teams were created and formed European student networks, which some of them are nowadays engineering professional networks. Students learned to develop engineering solutions also for nontechnical, multidisciplinary problems.

This paper summarizes the advantages and challenges of running IP’s, and proposes how the IP’s could be revitalized without external funds.

**POSITIVE RESULTS**

The teacher's role in IP differed from the traditional one. They could observe the professional development of the team members when supervising the design and implementation work. All IP partners had similar technical field. However, emphasis was quite different in each curriculum. Orientations concerning system analysis and design are also different. As the topic was chosen to be a real world multidisciplinary solution problem, different kinds of approaches were needed. The IP provided the possibility to apply the approaches developed at each partner institution to a practical application problem.

The project topic or task was multidisciplinary. In this case, the students had to focus on the solution and they were given proper tools, which they had to adapt quickly. Multidisciplinary top down engineering thinking along with Active Learning methods (CDIO Standard 8) was to be used and some technical details were taught ‘just on time’ basis. Similar approaches are spreading through in engineering education. Running IP’s help co-designing new pedagogical approaches, which each partner institute may freely adopt. This way the IP serves also as an international training session to enhance faculty competence and faculty teaching competence (CDIO Standards 9 &10).

Planning of the project was done by a group formed of representatives of all the partners, chaired by the coordinator. That work group made all the needed decisions and definitions. All partner universities were responsible for the tasks that were organized and divided on the meetings prior the IP. Supervision of students during the project was shared by all the partners’ representatives. Lectures were provided by teaching staff appointed according to
the special subjects. The main supervision in the Engineering Workspaces (CDIO Standard 6) for the students’ group work was provided by specially appointed staff members of the local organizer.

As there have been multiple IPs with the same partner universities, the transnational cooperation works without any problems or special concerns. The effectiveness of the approach where each partner university brings its special knowledge to the IP and actively participates on the student group work was highly effective. Each of the partner universities selected the students from their own organization based on their local criteria. Students were required to have genuine interest and proper fundamental knowledge on the topic. Applicants were ranked by their overall study performance.

Transparent distribution of the funds was ensured by sharing the budgetary information with all the partners, and agreeing on the use of the funds. Typically a round of an IP was funded by Erasmus with 50 000 - 75 000 € depending on the number of participant students and teachers, the duration of the intensive weeks and distance between their home - host locations. Accommodation was organized centrally and paid from the funds by the coordinating institute. Travel costs were collected by each institute, and then the coordinating institute was invoiced for these expenses according to the IP funding rules (75%). The project organization rate was used to miscellaneous expenses resulting from the physical implementation of the IP.

Students participating on the IP reported that the IP was an eye-opening experience (Piironen et al., 2014). This was due to the multi-disciplinary approach where students were forced out of their comfort zones and were required to collaborate with team members. For teachers, the IP was deepening long lasting relationships and was providing an opportunity where teachers could freely open discussions on various topics. A few international joint projects were initiated. The IP strengthened the partnership between the universities. In many cases the IP gave a conceiving ideas for curricula or course content enhancements. In the academic world there are rarely, hardly ever, an opportunity to develop new course content with 10 - 20 colleagues in an international context. Often the subjects were focused on emerging technologies that were not yet a part of regular curricula. Subject was selected to be multidisciplinary and comprehensive. It can be seen new trends concerning both in content and pedagogical approach. International aspects, comparison of teaching methods and benchmarking should be mentioned as objectives of IPs, as well.

The results of most evaluations were very favorable. Commonly there was only a little room to improvement except on the matters related to the facilities, equipment, and tools available. However, from the learning point of view, this forced the students to be innovative and use alternative solutions.

The School of Information and Communication Technology at Metropolia University of Applied Sciences participated in 17 different IP programmes counting altogether 41 rounds. Each round gave an opportunity to 10 students from each partner university to participate. Roughly 400 Metropolia students had a chance to gain an international learning experience in these IP’s. Counting all European mobile students and teachers would total to 2500 students and 400 teachers participating in these IP’s as listed in Table 1.
## Table 1. List of Erasmus IP programmes where Metropolia School of ICT participated.

<table>
<thead>
<tr>
<th>IP abbreviation</th>
<th>Full name of IP</th>
<th>Years</th>
<th>Venues</th>
<th>Mobile students/staff</th>
</tr>
</thead>
<tbody>
<tr>
<td>DaSBuG</td>
<td>Data Science for Business and Government</td>
<td>2014</td>
<td>Riga (LV)</td>
<td>50/18</td>
</tr>
<tr>
<td>HESUDI</td>
<td>HEalthcare Support Using Domotics and IT</td>
<td>2014</td>
<td>Helsinki (FI)</td>
<td>60/12</td>
</tr>
<tr>
<td>Active Games</td>
<td>Active Games</td>
<td>2013 - 2014</td>
<td>Frankfurt (DE), Vilnius (LT)</td>
<td>60/12</td>
</tr>
<tr>
<td>Big Data</td>
<td>Big Data</td>
<td>2013 - 2014</td>
<td>Vilnius (LT), Frankfurt (DE)</td>
<td>50/18</td>
</tr>
<tr>
<td>ViOpe</td>
<td>Learning Computer Programming in Virtual Environment</td>
<td>2013 - 2014</td>
<td>Espoo (FI), Leiria (PT)</td>
<td>60/14</td>
</tr>
<tr>
<td>LBS</td>
<td>Local Based Services</td>
<td>2012 - 2014</td>
<td>Sundsvall (SE), Amsterdam (NL), Istanbul (TR)</td>
<td>60/14</td>
</tr>
<tr>
<td>SaSeRoS</td>
<td>Safe and Secure Robots based on Open Source Software</td>
<td>2012 - 2014</td>
<td>Valencia (ES), Espoo (FI)</td>
<td>50/12</td>
</tr>
<tr>
<td>SWEB</td>
<td>Secure WEB Applications: Best Practices for Protection and Development</td>
<td>2012 - 2014</td>
<td>Munich (DE), Glamorgan (UK), Cantabria (ES)</td>
<td>60/12</td>
</tr>
<tr>
<td>DOSSEE</td>
<td>Developing Open Source System Expertise in Europe</td>
<td>2011 - 2013</td>
<td>Espoo (FI), Alcala (ES), Kapfenberg (AT)</td>
<td>60/15</td>
</tr>
<tr>
<td>EPSIAE</td>
<td>European Project for Sustainable ICT in Academic Education</td>
<td>2011 - 2013</td>
<td>Amsterdam (NL), Amsterdam (NL), Birmingham (UK)</td>
<td>60/12</td>
</tr>
<tr>
<td>WISDOM</td>
<td>Web Information System Data Organisation Modelling</td>
<td>2011 - 2013</td>
<td>Vilnius (LT), Porto (PL), Helsinki (FI)</td>
<td>50/18</td>
</tr>
<tr>
<td>eDSP</td>
<td>Embedded Digital Signal Processing IP</td>
<td>2010 - 2012</td>
<td>Espoo (FI), Vilnius (LT), Coventry (UK)</td>
<td>40/12</td>
</tr>
<tr>
<td>Miss Logo</td>
<td>Management Information Systems Supporting LOcal GOvernment</td>
<td>2008 - 2010</td>
<td>Mechelen (BE), Eindhoven (NL), Vilnius (LT)</td>
<td>50/18</td>
</tr>
<tr>
<td>Outsourcing</td>
<td>Nearshoring: the Next Step in Offshoring</td>
<td>2008 - 2010</td>
<td>Cracow (PL), Ostrava (CZ), Sundsvall (SE)</td>
<td>60/14</td>
</tr>
<tr>
<td>DeSeRTS</td>
<td>Design of Safe and Reliable Technical Systems - Exploring technologies dark sides</td>
<td>2007 - 2009</td>
<td>Bonn (DE), Espoo (FI), Amsterdam (NL)</td>
<td>60/12</td>
</tr>
<tr>
<td>Security</td>
<td>Improving the Security Knowledge in ICT - Advanced Technologies</td>
<td>2007 - 2009</td>
<td>Espoo (FI), Amsterdam (NL), Paris (FR)</td>
<td>60/15</td>
</tr>
<tr>
<td>QA-ICT</td>
<td>Improving the success of the ICT projects, Quality Assurance</td>
<td>2005</td>
<td>Amsterdam (NL)</td>
<td>60/10</td>
</tr>
</tbody>
</table>
CHALLENGES

One common challenge of multinational educational projects is to match the intensive project such that it does not disturb student’s regular studies or traineeship period. This challenge was overcome by agreeing on the timing of the IP as one of the first co-operative planning efforts.

The main challenge is to find sufficient funds. Although Erasmus IP program enabled these intensive projects, there was not enough momentum to continue activities after funding was over. With the grant we could support 75% of the travel costs, 100% of student’s accommodation, and subsidize partly student’s meals. The grant could not be used for wages, which was one of the major expenses. On the other hand the IP produced credit points for students, which is the main purpose for operating a university.

Surprisingly also recognition of IP credits as a part of student’s curriculum in degree programme required sometimes extra persuasion. Typical excuses were “full curriculum with no room for optional studies at all” and “IP was not on the curriculum during the last accreditation time”. Although the professors of degree programmes were involved on the development of the IP, it seemed that there was some kind of communication gap in between the department and student affairs office.

CONCLUSIONS

The benefits of organizing multinational intensive projects is evident. However, some issues must be solved first before we can realistically start intensive projects in large scale again. The intensive project should be made a part of regular curriculum. However, since we cannot realistically organize massive intensive periods abroad, it should be an optional part of the studies. Modern communication and social networking tools offer an interesting opportunity to virtualize the mobility part of the IP. Nowadays anyone with decent connection to internet can do video conference calls, live video broadcasting, co-editing documents, transfer files, send quick messages, co-scribble whiteboards, and do almost anything which required a physical working area just a decade ago.

We are looking for few brave partners to start developing the IP concept to a new level. All challenges are solvable if we just find the common desire to start doing instead of just continuing the discussions.
REFERENCES


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.

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PEDAGOGY FOR EVIDENCE-BASED FLIPPED CLASSROOM – PART 2: CASE STUDY

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ABSTRACT

This paper shows how a pedagogical framework for designing a flipped classroom using an evidence-based approach supported by creative use of info-communication technologies (ICTs) tools in being applied to a Year 3 core module in an engineering curriculum, Plant Safety and Loss Prevention from the Diploma in Chemical Engineering, Singapore Polytechnic. The paper firstly presents a brief introduction of the module and its learning outcomes; and the use of a chemical process plant lifecycle approach in teaching the module. Next, the pedagogy for flipped classroom is introduced, with detailed explanation on how the key elements in the flipped classroom framework (introduced in Part 1) is translated in practice to the designing and sequencing of learning tasks into pre-class activities and in-class activities. This serves as the basis in planning the entire student learning experience, which is achieved using the core principles of learning embodied in the flipped classroom framework. This include the consideration of what students already know, what else they need to know, what can they do to acquire the requisite knowledge, and what do they to do in class, the kind of evidence to be collected to demonstrate their learning, the opportunity for formative assessment (feedback), and the choice of ICT tools most suitable for the task at hand. Unique features of the approach to teaching chemical process safety and how an engaging in-class learning environment is created are shared, including approaches to scaffolding student learning via mock assignment, self- and peer marking using rubric and score sheet. Various approaches to create positive learning environment for students are also presented. The last part of the paper presents the first author’s reflections on the key learning points from the flipped classroom initiative followed by a discussion of areas of improvement to teaching the module.
KEYWORDS

Flipped Classroom, Evidence-based Approach, Chemical Engineering, CDIO Standards 8 and 12

FLIPPED CLASSROOM FOR TEACHING CHEMICAL PROCESS SAFETY

The application of flipped classroom in higher education had been adopted in various disciplines and had been broadly presented by Cheah and Sale (2017). This paper presents a case study on the work done in teaching chemical process safety (entitled Plant Safety and Loss Prevention) using a flipped classroom approach, using the framework suggested by Sale and Cheah (2017), as shown in Figure 1.

Figure 1. Framework for Evidence-based Flipped Classroom

The module is a Year 3 Diploma in Chemical Engineering core module (60 hours, fully in-course assessment, i.e. no examinations) taught to all 120 students in Semester 1 of an academic year. The module is taught over a period of 15 weeks using case study as the core pedagogic method. Contact hours are 4 hours per week which is devoted to classroom activities designed to engage students in applying the concepts learned during the online components. The main learning outcomes from the module, which frame the type of assessment evidence to be derived from the various student activities, are:

1. Identify from the assigned cases the correct safety issues at the proper stage of the chemical plant lifecycle
2. Infer and interpret probable causes that can lead to deviation from safe operating conditions and predict likely consequences or damages
3. Apply the correct preventive or mitigation strategies to prevent the occurrence or minimize the impact of any occurrence of a chemical process hazard
4. Transfer key concepts and principles from analysis of earlier cases to new cases presented at a later part of the semester
The teaching of the module uses a chemical plant lifecycle approach as shown in Figure 2 (Cheah, Lee & Sale, 2016).

The lifecycle approach is adapted from the one used by the American Institute of Chemical Engineers, AIChE (Hendershot, 2011), which shows that a typical chemical plant goes through 5 key stages from its inception during R&D and process development, through to design and operation, and end with its eventual retirement and disposal. Added to the lifecycle diagram are chemical and process hazards shown above the lifecycle, and the loss prevention measures available to identify the hazards, evaluate the risks associated with the hazards, and preventive measures that can be taken to minimize the risks. A key theme that ran across the entire plant lifecycle is the emphasis on inherently safer design (Kletz, 1991).

**PEDAGOGY FOR FLIPPED CLASSROOM USING EVIDENCE-BASED APPROACH**

With Figure 2 setting the overall “direction” of teaching chemical process safety, we use the framework as shown in Figure 1 to design the flipped classroom for the entire 15-week duration of the module. Broadly, the outcome can be represented by the approach shown in Figure 3. The first and second columns show the 2 components of flipped classroom – the pre-class preparation and in-class activities, while the third column shows the assessment approaches to gather evidence of learning, and the last column show the role of EduTech tools that support the learning process.
Pre-Class Activity

As shown in column 1 of Figure 3, students gain disciplinary knowledge outside of classroom (as Pre-Class Activity) needed for in-class discussion by watching online videos of the lecture materials, supplemented by resources from the web site of the U.S. Chemical Safety Board. Students can also engage in other pre-class activities such as reading of selected journals, information curated by the lecturers, or do actual visit for selected laboratory/workshop. Students get to assess their own learning by answering a series of self-evaluation questions – usually a combination of true/false and multiple choice questions (MCQs). These are shown in column 3 of Figure 3, and is formative in nature – the assessment is not graded, and students get immediate feedback on their effort, with short notes providing explanation on the selected response regardless of whether a correct or wrong answer is given. The ICT tools used are shown in column 4 of Figure 3, for example, the online videos are created using PowerPoint with narratives, and the self-evaluation questions are created using Socrative. Socrative is able to compile the necessary statistics that capture as evidence how well students grasped the content of their pre-class preparation. The lecturer can view these submissions before class, and accordingly address any issues that may surface.

Figure 3. Pedagogy for Flipped Classroom using Evidence-based Approach

Approach to Learning Chemical Process Safety

Before proceeding, it is worth mentioning that we used case studies as the method of choice in teaching chemical process safety, which had been identified by many educators as an effective method (Shallcross, 2013). In our approach, we use the Bhopal Gas Tragedy of December 1984 as the “anchor” case study, supported by several other high-profile accidents (e.g. Piper Alpha, BP Texas) to demonstrate how hazards may arise at different stages of the chemical plant lifecycle, and how the techniques taught in the module can be applied to mitigate the risks associated with the hazards. Students are then required to apply
what they learnt from the Bhopal and these other cases to other case studies. As these high-profile incidents are already very well documented, it is relatively easy for students to go to Google to look for model answers if we used the traditional “Learning from Accidents” approach to teaching chemical process safety, such as discussion of the chain of events that occurred, the key lessons learnt, and recommendations to avoid future occurrence. Instead, by using the plant lifecycle approach, we make it more challenging for students as they had to first analysed a case to pinpoint the specific stage of the plant lifecycle when the accident occurred, the specific hazards that existed, and how the risk could have been reduced had proper measures been taken not only at that given stage, but in earlier stages where there are more opportunities for implementing an inherently safer design. In this manner, we ensure there is a better transfer of what is learnt in earlier lessons to later ones. With this, we wish to avoid the pitfall noted by Pitt (2012): “The official 'lessons learned' can be pasted in or even memorized for the exam but not applied elsewhere.”

In addition, we also prepared our own cases, based on a fairly common chemical process available in all refineries – the amine treating system, used for removing sulfur compounds in kerosene and diesel products. The chemical processing industry is known for its adoption of advanced technologies, many of which are proprietary. We firmly believe that learning chemical process safety needs to be done in the suitable context, and as such students need to know in sufficient detail a typical chemical process, and amine treating, in the judgment of the first author, fits the requirement nicely. The layout and equipment is very similar in all companies, so it can provide a good foundation on which students can study how chemical process safety is applied throughout the different stages of the plant lifecycle. Of course it is also very real-world focused. Another added advantage is that, epitomised by what the first author told students: “This is one case whereby you cannot find answers by 'googling'. You need to really understand the process and my lessons in order to apply the knowledge gained.”

**In-Class Activity**

When students come to class (column 2 of Figure 3), they are reminded on how the day’s topic fit into the overall picture as depicted in the advanced organizer (based on Figure 2), and shown the learning guide which provide a summary of the week’s lessons. The learning guides are made available in advance to students as part of pre-class online viewing of the recorded video. The lecturer, who would have previewed the students attempts at the self-evaluation questions, may conduct a mini lecture not more than 10 minutes addressing key challenges or misconceptions identified and may also administer a concept test (consisting of several MCQs using Socrative) to further ascertain that students fully understand the underlying concepts.

For in-class learning experiences, several high effect size strategies (Hattie, 2009) are adopted, including mass practice (effect size 0.60), feedback (effect size 0.73), classroom discussion (effect size 0.82), etc. Next, we plan out the in-class learning tasks. This is where the core principles of learning embodied in the Framework of Figure 1 is useful in guiding us in the design of learning tasks. For our evidence-based teaching (EBT) approach, we use the framework as shown in Figure 1 for planning the contents to be covered based on what students need to know, what they already know, what they need to do in class to demonstrate that knowledge, the kind of evidence to be collected to demonstrate learning, and the choice of info-communication technologies (ICTs) tools most suitable for the task at hand. In this manner, the students’ learning can be appropriately scaffolded and timely feedback can be delivered. As can be seen in Figure 3, the ICT tools of choice are Google
Doc and Padlet. Google Doc allows online collaboration among team members and a jointly reasoned response is then presented. Padlet is akin to a digital Post-It Note and allows individual students to share his/her thoughts regarding the case being analysed. Students’ responses are captured and shown in real-time in class. This serves as evidence to the students understanding of the topics covered and allows the lecturer to immediately point out any misconceptions or rectify any deficiencies in understanding. With good reflective practice, it also enables the lecturer to review his own teaching of the topics and make improvements. Feedback is also given in real-time based on the students’ contributions to the discussion. In this manner, students continually build up their knowledge base and competency in applying them. This is supported, over the week(s), by self-paced learning tasks outside of classroom, as well as mass practices and also a mock assignment.

Lastly, as shown in Figure 3, a “milestone” is reached where a summative assessment is administered. Figure 4 shows a more concrete example of the work done for the module, in this case, a 6-week lesson plan using this approach is shown in Figure 4.
### FLIPPED CLASSROOM

<table>
<thead>
<tr>
<th>Week</th>
<th>FLIPPED CLASSROOM Activities</th>
<th>IN-CLASS ACTIVITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Inherently Safer Design (ISD), Management of Change (MOC) + Selected Journal Articles e.g. AIChE</td>
<td>Flixborough Incident, Chemical Process Plant Lifecycle as Advance Organizer Bhopal as “Anchor” Case</td>
</tr>
<tr>
<td>2</td>
<td>Layer of Protection Analysis: Basic Process Control System, Alarms &amp; Intervention, Safety Instrumented System</td>
<td>Bhopal &amp; Piper Alpha ISD &amp; MOC; Introduction to Amine Treating Unit (ATU) Process Flow Description (PFD)</td>
</tr>
<tr>
<td>3 (cont'd)</td>
<td>ATU Concept Checkpoint on BPCS &amp; SIS Discussion: BPCS &amp; SIS to ATU HP Absorber</td>
<td>Google Doc: Discussion on ATU BPCS + SIS Peer Marking of Mock Assignment w/ Rubrics</td>
</tr>
<tr>
<td>4</td>
<td>Layer of Protection Analysis: Pressure Relief System Site visit to W318 DPP PRS Indepth Learn: Relief Sizing</td>
<td>LOPA: BPCS, Alarms &amp; Intervention, SIS – Discussion on Bhopal, application for Distillation Pilot Plant (DPP)</td>
</tr>
<tr>
<td>5</td>
<td>Hazard &amp; Operability Study (HAZOP), Self-Learning ATU Malfunction Exercises</td>
<td>LOPA: BPCS, Alarms &amp; Intervention, SIS – Discussion on Bhopal, application for Distillation Pilot Plant (DPP)</td>
</tr>
<tr>
<td>6</td>
<td>Continue HAZOP Continue Self-Learning ATU Malfunction Exercises, and peer sharing on findings</td>
<td>HAZOP: Discussion on Bhopal, Piper Alpha, BP Texas, Application to DPP</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HAZOP for ATU: Mock Study for LP Absorber + Briefing on Rubrics for HAZOP Study</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mock HAZOP Peer Marking w/ Rubrics for LP Absorber Interim Module Summary Briefing on Week 7 MST</td>
</tr>
</tbody>
</table>

**Figure 4.** Sample 6-week Lesson Plan

Continuing the discussion, now using Figure 4 as example, in-class discussion is carried out with the lecturer using the Bhopal and other cases to highlight safety issues relevant to the day’s lesson and engage students in discussing how to resolve the issues using what they had learnt online prior to class. The discussion then moved to more in-class activities where new cases are introduced. Students working in teams get to apply their knowledge to these new cases by discussing the issues and/or offer solutions as dictated by the design of each case.
Creating Supportive In-Class Learning Environment

This can be created in several ways using the core principles of learning. One is through scaffolding and careful sequencing of the topics to be learnt. As noted above, one of the biggest challenges in this module is the students’ lack of real-world experience working in a chemical plant. The system we used is the Amine Treating Unit (ATU) from EnVision, a dynamic simulation software used for the training of process technicians and engineers. We devote 2 weeks for students to learn the process, its control and safety systems, as well as operating the plant – virtually. However, even the ATU can be intimidating for one who had not worked before in a chemical plant. We therefore used the “chunking” approach to break the ATU up into smaller work units, each with its own set of self-assessment questions, and staggered the learning tasks to spread over several lessons, as shown in Figure 4. In a similar manner, topics in chemical process safety are also logically sequenced so that latter topics build on the earlier ones. Such “chunking” and sequencing help to reduce the cognitive load on students, making learning the topic manageable and meaningful (Mayer, 2002).

Each activity will require students to activate their prior knowledge gained in earlier activities. In this manner, the students are continually engaged in thinking critically about what they had learnt, hence promoting good understanding and mastery of the subject matter. And to strengthen students’ appreciation of the topics learnt, the lecturer introduced several “Let’s Get Real” segments in the classroom by means of picture collages showing various real-world safety protective systems.

Supportive learning environment is also created by providing the students learning with clear and yet challenging goals, and providing them with ample opportunities for practice. Using the EnVision dynamic simulation system, we created many optional self-paced learning exercises for students to practice on. They can learn the ATU process at their own pace – before the next in-class lesson that is – thus creating a sense of flexibility in managing their own learning. As seen in Figure 4, students are given several mock assignments, which allow them to understand the performance standard expected of them. The assignments come complete with marking rubrics, which were explained to students. They also went through a sample marking exercise using comprehensive assessment rubrics, guided by the lecturer. For the mock assignments, students get to mark their own scripts, as well as practising peer marking on another student’s scripts. They are also given custom designed score sheers, so that they can learn to give feedback to each other.

Supportive learning environment can also be created by using formative assessment to guide students towards the learning goals. In the current educational setting, there will be one or more summative (i.e. graded) assessment along the way, and this module is no exception. The assessment scheme for this module is shown in Table 1. With our evidence-based approach, feedback and ‘learning checklist’ are used regularly and consistently as formative assessment so that students can monitor their own learning. As can be seen in Figure 2, lessons are organized so that they progress toward the stage where a graded test or assignment (summative assessment) is due. For the subject Plant Safety & Loss Prevention, the students need to take a 1-hour mid-semester test (individually graded, worth 20% of total coursework) and submit a HAZOP study report (group work, worth another 20% of total coursework).


Table 1. Assessment for Plant Safety & Loss Prevention

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Percentage of Total Grade</th>
<th>Type</th>
<th>Week Due / Administered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid-Semester Test</td>
<td>20</td>
<td>Individual</td>
<td>7</td>
</tr>
<tr>
<td>HAZOP Assignment</td>
<td>20</td>
<td>Group</td>
<td>9</td>
</tr>
<tr>
<td>Independent Study Assignment</td>
<td>15</td>
<td>Group</td>
<td>11</td>
</tr>
<tr>
<td>Presentation on Engineering Ethics</td>
<td>15</td>
<td>Group</td>
<td>14</td>
</tr>
<tr>
<td>End-of-Semester Test</td>
<td>30</td>
<td>Individual</td>
<td>15</td>
</tr>
</tbody>
</table>

Before rounding off this section, mention needs to be made regarding the proposed pedagogy for evidence-based flipped classroom. The approach in Figure 3 is meant to provide a systematic way of planning the flipped classroom taking into consideration the topics to be learnt, the assessment evidence to be collected, and the choice of ICT tools to be used to gather such evidence. It is applicable to any duration of study – and not restricted to a 6-week lesson plan as we shared above. The duration needed should be based on the level of difficulty of topics to be covered, and the lecturer would be the best person to adjust it to suit his/her teaching needs. A short topic may only need 2-3 weeks, while a challenging one, like the one for Plant Safety & Loss Prevention above, required up to 6 weeks to so that students develop sufficient understanding to tackle the HAZOP assignment.

**REFLECTION AND LEARNING POINTS ON FLIPPED CLASSROOM**

This is the second time the module is taught via flipped classroom approach by the first author. In terms of being able to engage students in their learning, the author opined that this approach is successful. As noted by Sale & Cheah (2017) earlier, today’s students – the Net Generation, i.e. the millennials – are different from students of yesteryears, and as such cannot be engage using the same methods. Lecturers need to change the way they teach to suit the way these millennials learn (Skiba & Barton, 2006). As aptly pointed out by Oblinger & Oblinger (2005): “Whether the Net Generation is purely a generational phenomenon or whether it is associated with technology use, there are a number of implications for colleges and universities. Most stem from the dichotomy between a NetGen mindset and that of most faculty, staff and administrators”. On this regard, it is important for lecturers – typically from the Baby Boomers and Generation X – to change their mindset, especially in the way one teaches: not least of all, in using ICT tools to aid in one’s teaching. Vaughan (2014) opined that “the integration of technology into the higher education classroom presents an opportunity to transform traditional pedagogy so that it reaches millennial learners”. Ironically, it is also the use of technology that many lecturers – the ‘Digital Immigrants” (Prensky, 2001) – are most apprehensive about. It would appear that lecturers are lacked the knowledge regarding the affordance of ICT tools and overly worried about having to learn new skills in computer technology, the approach of which is very different from the way they were once educated. Many lecturers are worried that they need to spent time – which they do not have – to develop new teaching materials from scratch. As well, many are also intimidated by the myriad of ICT tools available – over issues such as not sure which tool to use for which purpose, required learning curves, and support from school or department. This fear is aptly captured by Ross, Morrison & Lowther (2010) who noted that “the more options teachers have for improving lesson quality, the greater the demands for organizing or ‘orchestrating’ many diverse instructional activities”.

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Lecturers’ mindset towards ICT tools need to change, and the first step is to recognize that “educational technology is not a homogeneous ‘intervention’ but a broad variety of modalities, tools, and strategies for learning”. Its effectiveness, therefore, depends on how well it helps teachers and students achieve the desired instructional goals (Ross, Morrison & Lowther, 2010). In our own experience with flipped classroom, we recommend one to start with professional development programs from one’s own institution (such as that offered by the Department of Educational Development or equivalent) if these are available. Otherwise, one can choose to enrol in one of the introductory online courses on using Web 2.0 Tools such as Coursera, Edutopia, Udemy, or others. Rounding up several like-minded colleagues will provide the added momentum and “peer-pressure” to complete the programme.

Another mindset change needed on the lecturer is to get accustomed to the new role as facilitator of learning. Lecturers need to learn to “let go” of the perceived control they have in a flipped classroom. Lecturers must learn to be more situational and be able to respond to questions beyond “standard textbook answers”. More importantly, lecturers must have the humility to acknowledge that he/she does not have all the answers. The most important reply then is to give the student credit for asking a good question, and be sure to get back to the student with an answer as soon as practical, preferably by the next class. Bates & Galloway (2012) described the payoff for this approach as “the potential for an inclusive and participatory classroom atmosphere”. We may be increasingly moving towards what Fullan (2013) called the “new pedagogy” where students and teachers are now partners in learning.

Organising a community of practice for professional sharing can be a way to encourage more lecturers to change their way of teaching.

The introduction of any new strategy requires a shift in the minds of students as well. Talbert (2012) suggested that students who come from an educational background where lecturing and rote work is the norm may experience a great deal of culture shock at the flipped classroom and resist taking on the responsibility for learning that the method entails, feeling that they are being abandoned to learn the material on their own. To address this, the lecturer need to be prepared to gather lots of formative assessment data to watch for places where students may not be learning and to convince students that they are learning when appropriate. The first author certainly agreed with the advice offered by Silverthorn (2006) that the lecturer should tell students what he/she is doing and the rationale behind flipped classroom, and to periodically keep revisiting with students so that they truly understand the intention.

The flipped classrooms require students to assume more responsibility for their individual learning experience. An often raised concern is to get students coming to class prepared – they should have watched the recorded lectures, did the necessary reading, etc. Williams & Williams (2011) noted that “very little if any learning can occur unless students are motivated on a consistent basis”; and identify five ingredients as key to student motivation: the student themselves, teacher, content, method/process and environment. Indeed, the very success of flipped classroom depends a great deal on student motivation to prepare themselves before coming to class. Given our experience in this flipped classroom journey, the first author feels that the team had done sufficiently well in using the framework in Figure 1 in addressing the in-class component of flipped classroom. The second author’s classroom observation of lessons by the first author seems to support this. A key area that needs improvement is the online component. The team feels that this is the area where student motivation is still lacking. More will be elaborated in the next section on how the viewing of lectures can be incentivized (Gannod, Burge & Helmick, 2009).
Equally important, as reported by McCallum, et al (2015), students themselves expressed concerns “about the increased self-discipline required for participating in a flipped classroom.” This is indeed the comments the first author received from some students, especially on the week where there is another assignment due from another module, for example. In this case, the students tend to “optimize” their available time based on the perceived relative importance of competing requirements from different modules.

In any case, the first author suggests that the lecturer stands firm on not repeating the lecture in class. It may be frustrating at first if we have to go on with lessons with half the class (or more!) not prepared, but if we persist, the whole class will soon “get it”.

Lastly, from the first author’s perspective, although implementing flipped classroom is time-consuming in terms of the preparatory work required (e.g. video-recording, designing in-class activities, including various rubrics), the experience had been more enriching and rewarding. In today’s world where the often quoted reasons for not carrying out the long overdue curriculum revamp is that there is insufficient time to cover all the materials that students need to learn; flipped classroom actually permits freed up precious classroom time. The key is not to make use of the available classroom time to teach more content, but to engage students in applying what they learnt, and hence deepening their learning – the stuff that really matters. As noted by Bates & Galloway (2012): “It is an exhilarating feeling to be freed from the tyranny of content coverage to be able to have the time and space to focus on what really matters…. Furthermore, this understanding did not come with a price of ‘covering’ less material: we are convinced that, largely through the students’ efforts outside class, we covered as much content but uncovered a great deal more understanding”. This is especially satisfying for lecturers who viewed themselves as “designers of learning” (Friesen, 2009) in influencing student learning. These lecturers are able to design better learning experiences for their students in part because they conceive of teaching as fostering learning (Bain, 2004).

Overall, the experience in implementing flipped classroom had been very rewarding, as there was as much learning for the lecturers, as we research for resources to curate the resources needed for in-class activities and designing them.

RECOMMENDATIONS FOR FUTURE WORK

We conducted an evaluation of the evidence-based flipped classroom. The findings detailed elsewhere (Cheah & Sale, 2017). Suffice to note that our experience indicated that students are sufficiently engaged during in-class activities. This section focuses on the ideas for improvement in teaching the module. One of the feedbacks we obtained from students is that the video-recording can be boring at times. This is hardly surprising – a video recording of a lecture is still a lecture! As we transitioned from the usual lecture to flipped classroom, a priority of our initial emphasis is on designing meaningful classroom activities. These are more time-consuming than expected, so we chose the easiest approach for the lecture component and prepared recorded narratives within PowerPoint itself.

Now, after 2 semesters of teaching with the flipped format, and even though we still came up with a sizeable “punch list” of areas of improvement, we felt the time is due for a relook at how to make the online lecture component more engaging for students. As noted by Svinicki & McKeachie (2011): “In most courses students spend at least as much time studying out of class as they do in class. Thus, you need to focus as much on what you expect students to do outside class as on what goes on in class”. Baepler, et al (2014) suggested that the pre-
class assignments served as the structure needed to engage with course content more deliberately, hence careful planning is needed. Likewise, Gross, et al (2015) argued that student success in flipped classroom results from the close coupling of in-class activities to online course content.

Our current practice is to supplement the recorded lectures with some reading of journals, additional videos from U.S. Chemical and Safety Board (www.csb.gov), YouTube, etc. Students then engage in activities during class time. We did not provide the questions for students to prepare before coming to class. Heiner, et al (2014) suggested that we be specific in our approach; for example, in required reading – by directing students to look at specific figures and/or pages. The authors also suggested that any quizzes given should be graded if possible, and that this is best done online and not during class. At the moment, the questions we posed using Socrative is meant for self-evaluation by students, not as a mean of assessment or grading, and as such were not graded. Initially we are rather hesitant to award marks that contributes toward final grading, as this seems like a form of extrinsic motivation. However, in this case, the reward may be justified, as noted by Pink (2011), as it “can provide a small motivational booster shot without the harmful side effects.”

Next, we plan to replace the recorded lessons with microlectures. A microlecture is short recorded audio or video presentation on a single, tightly defined topic” (EDUCAUSE, 2012). Sweet (2014) noted that microlectures are generally comprised of a lecture or demonstration, a narrated slideshow, or a screencast accompanied by a voiceover; are useful for flipped classroom, for example, by providing students with small chunks of new information necessary before in-class discussions, or to pique student’s curiosity and interest for a new topic prior to introducing it in class.

Lastly, there is also a need to evaluate the effectiveness of the learning designs of the online component: the pre-recorded lectures. Various authors had written about the usefulness of recorded lectures as supplementary to their usual lectures, for example in allowing students to catch up on missed lessons, and to study for examinations (e.g. Whatley & Ahmad, 2007; Gorissen, et al, 2012). Gysbers, et al (2011) reported that students will attend lectures despite the availability of online recording because they value the learning environment afforded by live lectures. Students consider attendance at lectures as value-adding and provide the required discipline in their study program; and consider live lectures as integral part of the contemporary university community experience. However, the use of recorded lectures in flipped classroom, where students are required to first view and learn the contents prior to coming to class, is a relatively new phenomenon and is not yet widely studied. Anecdotal evidence from this work suggested that some students managed to “get by” during some of the in-class activities. These students appear to only use the online materials for revision before the mid-semester or end-semester tests. It will be of interest to investigate the efficacy of the microlectures used in the flipped classroom context. A possible approach is to use scholarly framework such as the SAMR Model (Romrell, et al, 2014) as suggested by Mazur, et al (2015).

**CONCLUSION**

This paper provided a case study how a framework for evidence-based flipped classroom is being applied to a core module in the Diploma in Chemical Engineering. A structure for organizing the online and in-class components, along with the choice of ICT tools that best deliver the needed evidence to demonstrate student learning is provided. Examples of lesson
plan and how scaffolding is systematically applied is shared. Based on reflections on work done, we would like to suggest that the approach shared in this paper is a viable way to engage students in learning about chemical process safety; and that the same approach can be extended to higher level of learning (undergraduate and beyond) to develop competent safety professionals that meet the needs of the chemical processing industries. The evidence-based flipped classroom approach had enabled the required learning to take place, and the framework used in its design allows for continual improvement.

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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. He currently teaches the module Plant Safety and Loss Prevention. His academic interests include curriculum revamp, academic coaching and mentoring, and using ICT in education. He has presented many papers at the International CDIO Conferences.

Dennis Sale is the Senior Education Advisor from the Department of Educational Development at Singapore Polytechnic. He has worked across all sectors of the British educational system and provided a wide range of consultancies in both public and private sector organizations in the UK and several Asian countries. He has authored two books and had conducted numerous workshops in all educational contexts in many countries, and presented papers at international conferences and published in a variety of journals and books.

H.B. Lee is Senior Lecturer in the Chemical Engineering Division, School of Chemical and Life Sciences, Singapore Polytechnic. She has recently taken up the role of Academic Mentor, under the Teaching and Learning Unit, to further her interest in educational pedagogies and module development. She is also actively involved in the maintenance of environmental management system, a portfolio she holds with the Organisation Development and Facilities Management Division of the School.

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PEDAGOGY FOR EVIDENCE-BASED FLIPPED CLASSROOM – PART 3: EVALUATION

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ABSTRACT

This paper shares the results of an evaluation of flipped classroom, which had been implemented in a Year 3 core module entitled Plant Safety and Loss Prevention from the Diploma in Chemical Engineering (DCHE) for the past 2 years. The flipped classroom was designed using an evidence-based teaching approach supported by extensive use of info-communication technology (ICT) tools. The paper firstly provide a brief but concise literature review of the flipped (also known as inverted) classroom approach and its use in different fields of study. Given the conflicting findings to-date, this paper strives to provide a balanced view of the relative merits of the approach, as well as challenges faced from both the perspective of faculty and students. The paper then shares the approach taken by the authors who designed a comprehensive blended learning research to qualitatively assess the effectiveness of flipped classroom as applied in the context of the above said module. Specifically, the authors are interested in identifying which features of the learning designs have significantly impacted student learning (e.g. positively, negatively or other), and on what basis. The research lasted 6 weeks, implemented from mid-April till end-May 2016, although flipped classroom was implemented for the entire 15-week duration of the module. Students are selected to take part in the research as co-participants, providing regular feedback on their learning experience. The first author who conducted the lessons, regularly reflected on his teaching practices, and often made improvements to his teaching materials within days upon the conclusion of each lesson. Lastly, the paper shares the findings from the study, and limitations of current work. It concludes with our frame on the state of flipped classroom and our plans to move forward in this exciting new educational approach.

KEYWORDS

Flipped Classroom, Evidence-based Approach, Chemical Engineering, CDIO Standards 8 and 12
FLIPPED CLASSROOM: ADVANTAGES, DISADVANTAGES & CHALLENGES

In recent years, flipped classroom (also known as inverted classroom) is gaining popularity among educators around the world (Seery, 2015). It was widely attributed to the effort of Baker (2000) and also Lage, Platt & Treglia (2000); and popularized by Bergmann & Sams (2012). Since then, there had been many publications attesting to the usefulness of flipped classroom in improving various aspects of students learning (e.g. Herreid & Schiller, 2013; Berrett, 2012), and many resources offering guidelines and tips for implementing flipped classroom (e.g. Moffett, 2014; Margulieux, Majerich & McCraken, 2013). Strayer (2012), in the teaching of statistics, noted that students in an such a classroom become more aware of their own learning process than those in more traditional settings; and reported increased student cooperation, innovation and task orientation. Based on analysis of self-determination theory and cognitive load theory, Abeysekera & Dawson (2015) suggested that flipped classroom can improve student motivation and help manage cognitive load. Other benefits claimed include increased students greater student engagement and satisfaction with the course of study (e.g. Strayer, 2012; Dove, 2013; Wilson, 2014), addressing misconceptions (Fautch, 2014), and improvement in meta-cognition (van Vliet, Winnips & Brouwer, 2015).

Examples of application of flipped classroom in various programs and courses are shared next, but these are by no means exhaustive. Flipped classrooms had been used in different science and engineering disciplines, for example computer engineering (Redekopp & Ragusa, 2013), mechanical engineering control systems (Mason, Shuman & Cook, 2013), digital engineering (Warter-Perez & Dong, 2012), electrical engineering (Papadopoulos & Roman, 2010), chemistry (Seery, 2015), physics (Deslauriers & Wierman, 2011), dynamics (Stanley & Lynch-Caris, 2014), and chemical engineering (Cheah, et al, 2016) etc. Velegol, Zappe & Mahoney (2015) also provided discussions of flipped classroom implementation in engineering education. Hawks (2014) reported on the use of flipped classroom by various faculty in the medical and health sciences, notably nursing education, medical education, pharmacy, etc. Flipped classrooms are also used in non-engineering courses, for example, in business (King & Piotrowski, 2015), spreadsheet (Davies, Dean & Ball, 2013) and entrepreneurship (Norrmman, et al, 2014). Some authors also noted that the use of flipped classroom allow them to cover more contents (Mason, Shuman & Cook, 2013). On student perceptions of flipped classroom, most authors reported positive responses from students (e.g. Redekopp & Ragusa, 2013; Butt, 2014; Murray, Koziniec & McGill, 2015; Seery, 2015). Interestingly, Sinouvassane & Nalini (2016) reported that year one students are more open to accept the flipped classroom model when compared to third year students. For more examples, readers are encouraged to refer the works of O'Flaherty & Phillips (2015) who provided a concise summary of outcomes from 28 flipped classroom initiatives.

Given the positive vibes surrounding flipped classroom, Goodwin & Miller (2013) went further to claim that it is not just the classroom that had been transformed, but the entire paradigm of teaching, i.e. away from a traditional model of teachers as imparters of knowledge and toward a model of teachers as coaches who carefully observe students, identify their learning needs, and guide them to higher levels of learning.

However, flipped classroom had its fair share of criticisms. Indeed, a review of current literature showed mixed results, although it is probably fair to say that, based on the publications to date, there are more positives than negatives. Betihavas, et al (2016) concluded that the use of flipped classroom in higher education nursing programmes has either increased or had no significant effect on student's academic performance. Mason, Shuman & Cook (2013) for example reported that the flipped classroom “at best improved
students’ understanding of engineering concepts” and that at worst “did no harm”. McLaughlin et al (2013) compared final exam scores of students and found no significant differences. Similarly, Whillier & Lystad (2015) reported that there is no difference in grades or level of satisfaction in a flipped classroom compared to traditional lessons. Likewise, Lape, et al (2014) reported that there is no improved student learning as a result of the inverted format as compared to an active-learning-based course format. In a recent publication, Jensen, Kummer & Godoy (2015) reported that flipped classroom does not result in higher learning gains or better attitudes compared to non-flipped classroom when both utilized an active learning, constructivist approach. These authors proposed that such gains are most likely a result of the active learning style of instruction rather than the use of flipped classroom per se. One of the strongest objections to flipped classroom is a view that it is “simply a time-shifting tool that is grounded in the same didactic, lecture-based philosophy. It's really a better version of a bad thing.” (Ash, 2012). Pienta (2016) noted that the literature is clear that flipped classroom, just like other form of active learning, requires engaged students. However, not all students are motivated to put in the required effort to learn lesson materials on their own before coming to class. Lacking “homework culture” (Straw, et al, 2015), these students may come to class unprepared to participate in class activities. Another challenge is the time and money demand on the part of faculty: to produce a flipped classroom required the digitization of lesson materials; and design of classroom activities for every class period.

EFFECTIVENESS OF FLIPPED CLASSROOM: WHERE IS THE EVIDENCE?

Despite its popularity and the above reported shortcomings, there is very little evidence about the specific merits of flipped learning and there had been calls more in-depth investigation of the effectiveness of the method. Bishop & Verleger (2013) for example, called for research with controlled studies that objectively examine student performance throughout a semester, with both traditional and concept-inventory style problems; and a theoretical framework to be used as a guide to the design of in-class activities. In their scoping review of 28 recently published work on flipped classroom, O’Flaherty & Phillips (2015) noted that very few studies actually demonstrated robust evidence to support that the flipped learning approach is more effective than conventional teaching methods. They also noted that whilst some studies referred to a modest improvement of academic performance, through outcomes of increased examination scores or improved student satisfaction, further research is required in this area with longitudinal cohorts evaluating the learning outcomes of utilising flipped approaches compared with traditional teaching methods. Abeysekera & Dawson (2015), based on their literature review in flipped classroom, reported that the publications are mainly in the form of conference proceedings, supplemented by a few journal papers. Most refer to case studies and none of them rely on particularly rigorous research designs. These authors claimed that the flipped classroom approach is “under-evaluated, under-theorised, and under-researched in general.” Likewise, Seery (2015) while noting that the “flipped learning approach is likely to be a significant teaching and learning method over the next decade” also called for a more robust framework to implementing flipped classroom.

Deubel (2013) cautioned that flipped classroom is just a different approach to instruction, and that “different does not equate to better”. Forsey, Low & Glance (2013) made reference to the “Hawthorne effects” where any change in operating procedures can produce increases in worker productivity and/or satisfaction, and henceforth to treat any survey results with caution. Likewise, Hamdan, et al (2013) noted that the flipped learning mode “might be one
way to enable learning” and should “by no means be thought of as a panacea for solving all educational issues”. Reviewing the available publications, Yarbro, et al (2014) noted that the flipped learning model “likely does not work in all contexts”. Gojak (2012) opined that the question on flipped classroom is not whether to flip or not to flip; but rather how to apply the elements of effective instruction to teach students both deep conceptual understanding and procedural fluency. She noted that “flipped lessons that simply demonstrate how to do a procedure do not encourage understanding, do not ensure that students will remember the procedure, and do not promote adaptive reasoning."

EVALUATING A FLIPPED CLASSROOM

One reason why it is so difficult to evaluate the use of flipped classroom is that there are many variables that existed in active learning, course materials etc that makes it impossible to attribute the success (or otherwise) of the flipped model to any one causal factor (Jensen, Kummer & Godoy, 2015). Van Sickle (2016) cautioned that students did not accurately evaluate their learning in course evaluations, and that student perception in flipped pedagogy needs further study. Our paper hoped to shed some light on the situation by proposing an evidence-based approach to evaluate the effectiveness of flipped classroom.

The approach we had taken is to understand, from the perspective of students, which elements of the flipped classroom best meet their needs in terms of helping them in their learning (Crews & Butterfield, 2014). This is important, because the quality of students' learning is closely related to their perception of their learning experience. Key aspects of the learning context, such as assessment, workload, independence, the quality of the teaching and the clarity of goals and standards are all closely related to the quality of learning they experienced (Ginns & Ellis, 2007). More specifically in our context, our research focused on the effectiveness of in-class activities designed using selected the following high effect size interventions and delivered using the “Russian Dolls” strategy (Hattie, 2009):

- Goals (Learning Outcomes) using Advanced Organizer (start-of-class) and Checklist (mid-point and end-of-class) – effect size: 0.40
- Classroom Discussion with Peer Influences – effect sizes: 0.82 and 0.53 respectively
- Worked Examples, Scaffolding and Space vs Mass Practice – effect size: 0.37, 0.53 and 0.60 respectively
- Feedback and Formative Evaluation – effect size: 0.73 and 0.68 respectively

Cheah, Lee & Sale (2016) had reported on their work done to flip a Year 3 core module in the Diploma in Chemical Engineering entitled Plant Safety and Loss Prevention. In that work we shared our initial experience in flipped classroom using an evidence-based teaching (EBT) approach. We had since completed a second run of the module, and had made key improvements to the teaching of the module based on the feedback received. Key amongst these is the refinement of our pedagogy for evidence-based flipped classroom. Details of the work done are presented in a separate paper for this conference (Sale & Cheah, 2017).

This paper presents the results of a fresh evaluation of students’ learning experience for this second run, using an evidence-based approach as the guiding heuristics for evaluating the instructional design and teaching practices, as well as the students learning experiences. There are 2 key components to the evaluation process. One is the use of students who volunteer as "co-participants" (Lincoln, 1990) in the research process. The aim is to unpack the components of their experiences and identify which features have most significantly
impacted their learning (e.g. positively, negatively or other), and on what basis. These students provide regular feedback on their learning, and that of classmates (where possible) through focus group interviews and questionnaires. The other component is that faculty reflective practice. Sale (2015) argued that evidence-based reflective practice involves more than personal reflections in isolation, but a structured thinking process (e.g. analysis and evaluation) using EBT principles in relation to all valid evidence sources (e.g. students, peers, peer observers). As a holistic process it enable a better understanding of the reality of classroom learning (e.g. what is happening, and how this is affecting the learning process). From this base, we can then creatively design and facilitate instructional strategies that have high predictive capability for enhancing the learning experience and attainment levels. Specifically, in evaluating the learning experience we are looking for the presence or otherwise of the following:

- Appropriate method use to maximize learning opportunities in this Situated Context (e.g. learning outcomes, learner profile, learning space and resource access)?
- Clear presentation of learning goal, purpose and expectations to these learners?
- Activation of prior knowledge and subsequent connection to new knowledge presented?
- Emphasis on the key concepts and principles underpinning understand of the topic area?
- Activities (e.g. questions) that facilitated the types of thinking necessary for building understanding?
- Variation in the modes and methods of information presentation and interaction?
- Application of practices consistent with human memory processes (e.g. chunking, linkages, rehearsal and review)?
- Use of Deliberate Practice (where relevant)?
- Use of formative assessment activities to provide quality two-way feedback?
- Rapport building Interactions that promoted a climate conducive to success and some fun in the learning process?
- An aspect(s) of creativity (e.g. story, humour, activity, presentation style, example) that enhanced Intrinsic Motivation?

This enables ongoing appraisal of the instructional strategy, evidence-based diagnosis of student learning, both in terms of attainment and experience. Based on the above heuristics, we crafted a series of survey questions for the student co-participants who provide feedback on their learning experience in Plant Safety and Loss Prevention. The module is taught over 1 semester of 18 weeks; made up of a 7-week of lessons (Term 1), followed by 1-week of Mid-Semester Test and a 3-week term break, and concludes with another 7-week of lessons (Term 2). Altogether they responded to two survey questionnaires (one on Week 4, and again on Week 8, after their mid-semester test on Week 7) and attend a focus group discussion with the second author (on Week 11). Questions asked in the questionnaire are shown in the Appendix A. From the EBT point of view, it is much preferred to obtain feedback from students in this manner, compared to the “traditional” approach of student feedback currently employed, which is only carried out at the end of each semester. The questions asked are shown in Appendix B.

SELECTED FINDINGS FROM STUDENT FEEDBACK

Our student co-participants have provided a wide range of data on different aspects of the flipped classroom experience, but only those of most significance to this context are presented here. Overall, students found the use of advance organizers useful, although
some found it difficult to understand at first. Students generally cite its usefulness in helping them to keep track of their learning progress and how various topics are connected to form the big picture. They also agreed that the use of self-evaluation exercises after every topic (multiple choice and/or true/false questions in Socrative) are useful. However, some students did not use these exercises the way we intended – they attempted the questions after the day’s lessons instead of doing it before coming to class! As for Google Doc, students reported that classroom discussion is very useful in helping them to learn, especially from each other. This also applied to the case studies where different questions were posed to different groups, so that each group must work on one aspect of the issues presented and jointly contribute to the solution of the whole problem. Here is a typical comment from one of the co-participants:

“Yes, the collaborative approach with regards to group discussion is indeed a much more interesting and engaging learning experience. This allows sharing of opinions and ideas, and allows each student to justify their way of thinking. With this, I was able to actively listen to others, and with their responses, make appropriate modifications to my answer in order to achieve a thorough learning …I am able to identify faults in my arguments and answers, thereby promoting a self-marking and self-accessing approach in my own learning.”

The “chunking” of information into smaller bits also proved useful in assisting students in managing their learning. This is especially the case for the virtual plant Amine Treating Unit (ATU) from EnVision Systems. It is a commercially available training package based on dynamic simulation, for use in training of process engineers and technicians in operations and troubleshooting of chemical plants. The ATU is used firstly to provide the necessary background knowledge for our students’ lack of real-world working experience in chemical plants; and secondly, to provide the context for applying safety principles learnt in the module. The requisite knowledge on ATU is quite significant, so “chunking” made it possible for students to learn about the plant based on sections of the plant, each of which performs a specific function. This approach, coupled with the use of rubrics for peer marking in a mock tests, enables students to do the necessary thinking to develop good understanding of the requirements of the module. The following examples, illustrate this:

“Peer Marking with Rubrics helped me gain a better understanding of this topic area as it guided me on how to assess my peer’s answer and hence, give her feedbacks on ways of improvement. In addition, I know what is the lecturer expecting when marking for our test papers too.”

“…teammates would be able to constantly provide feedback on the answering style of different individual, hence suggesting improvements for students to improve.”

Another method that facilitated student learning was the use of a distillation pilot plant (DPP) to activate their prior knowledge. The students had previously worked on the DPP in Year 2 in the module Separation Processes, focusing on principles of separating and purifying liquid mixtures to obtain relatively pure products. In the present module, we make use of the safety protective systems in the DPP to introduce them a new topic on Layer of Protection Analysis (LOPA) that they now need to learn. They reported that working on the problems based on the DPP served to reinforce their learning of LOPA. The response below captures this:

“It allows us to visualise first hand, how the LOPA concepts can be applied in the DPP plant. Furthermore, it allows us to make hypothetical improvements to the DPP plant so
that it encompass the LOPA concepts. This enhanced learning, as the team could discuss about the technicalities behind the DPP plant, and move on to applying LOPA.”

The DPP is utilized again for study of pressure relief systems. This time students are tasked to visit the laboratory and locate the relief valves installed in the DPP after going through the online lecture recording on pressure relief systems. The comment below clearly revealed that the student “got it”:

“Yes, I able to see how pressure relief system applied in a real plant. We realised that pressure relief valve normally installed at the top of a column and we able to understand theory behind pressure relief system are installed at that location.”

Another approach that proved successful with students is the use of “Let’s Get Real” moments during class. These are basically photo collages of the real safety protective systems used in the chemical processing industries. Students generally appreciate knowing how the various devices learnt actually looked like, as compared to symbol representations in the P&IDs (piping and instrumentation diagrams). One participants elaborated:

“Yes it is interesting and engaging for us because there are definitely a portion of us that are interested in joining the chemical plant upon graduation. In school, the resources are limited and the big solenoid valves, for example, is not found in school. Hence, it is very interesting to be able to know more about the real life plants in Jurong island because there are still a lot of things that we do not know or cannot see until we join the work force. I think that it is good to constantly relate the lesson to the real scenario because at the end of the study journey, we are supposed to be trained for the real world and not just a simulation example.”

From the lecturer’s perspective, these in-class activities provide valuable opportunities to walk around and listen to the students’ group discussions, which makes their thinking visible. In this way misconceptions can be quickly identified and dealt with and necessary checks in understanding performed. The lecturer now takes on the role of what McWilliam called “meddler in the middle”, who challenges students to think and understand differently (McWilliam, 2005). The lack of such affordance is made painfully clear in Week 3, which is a SP-designated “Home-based Learning” week, where students do not come to campus for lessons but work fully online from elsewhere. Due to the lack of face-to-face classroom interaction, its not possible to usefully ascertain students’ ability to sketch the proper engineering diagrams depicting how Safety Instrumented Systems can be implemented. On hindsight, it would have been more effective to ask students to submit their sketches for marking. This issue was only noticed a later week when another in-class activity was introduced that required students to build on this new knowledge in a different application. This immediately prompted the lecturer to conduct a mini-lecture to quickly bring the students “up to speed”.

On the other hand, the use of checklist drew mixed responses from students. The checklist was shown in class after 1 hour of lesson as mid-point summary and again at end-of-class summary. One student’s response was particularly interesting:

“No, the checklist (mid-point or end of lessons) has not helped myself as individual to keep track of my learning based on the lesson objectives …Even though, the use of a checklist does push me to think about the learning outcomes, it does not actually prove that I am indeed competent in these aspects.”
As things turned out, the lecturer often did not have sufficient time to go through the checklist in details with the class. On reflection, the checklist could have been included in the workbook instead for students to monitor their own learning, after they had completed all the activities of a given topic.

Lastly, this evaluation exercise also revealed several interesting insights. One insight gained is that students tend to ‘optimize’ their time devoted in the study process by balancing the activities designed for this module with the demand of other modules, especially those with examinations. There was one occasion where the students did not complete some simulation exercises for classroom discussion, and when inquired, they were quite frank in revealing the reason for non-submission was due to the need to submit an important assignment for another module on the same day. On a lighter note, it appears that the students – especially the co-participants – are very motivated by the involvement in this work, when they understand that we are truly interested in finding out how well are they learning the subject. This can be seen form the enthusiastic response (both postitives and negatives, as well as ideas for improvement) written for the surveys and during focus group discussion.

LIMITATION OF THE STUDY

This work focus on the in-class component of flipped classroom, specifically the effectiveness of various high effect size strategies in engaging students in their learning. One limitation of the research is that we have not investigated the efficacy of the online component, which is equally important. Currently just based on narrative of the usual PowerPoint slides using Camtasia, supplemented by occasional reading of selected journal articles or YouTube videos. As noted by Blui, et al (2007), the most significant need in blended learning research is information on how best to integrate the online and face-to-face portions of the course into a coherent whole. We also obtained a clearer picture of how student motivation can play an important role in coming to class prepared, when they had to juggle the demand from other module, especially those with examinations are often perceived to the of “higher stakes” than modules based on fully in-course assessment such as Plant Safety and Loss Prevention.

The teaching team had fully reviewed responses from students co-participants and immersed themselves in a reflective exercise on key learning points. We have reviewed the current state of teaching of chemical process safety, and am convinced that flipped classroom approach is an effective way for students to learn the subject. Key areas of improvement including the use of micro lectures to replace the present video-recording has been explored; and shared elsewhere (Cheah, Sale & Lee, 2017). Future work will also involve evaluation of student learning experience in the online component.

CONCLUSION

The feedback from student co-participants had shown that many of the strategies employed in the classroom in the teaching of Plant Safety and Loss Prevention via a flipped classroom approach are positively impactful in in supporting their learning, particularly the advanced organizer, use of Socrative for self-evaluation, and Google Doc for classroom discussion. On the other hand, the use of checklist has not been as effective, but this does not necessarily mean the method choice was inappropriate, but rather because it was not effective used. We also need to explore the design on the online or out-of-classroom component of flipped
classroom. As teaching is a highly complex and situated activity, it is always going to be heuristic, never algorithmic. However, the use of an EBT approach provides our best basis for useful heuristics as it is grounded in validated knowledge relating to how humans learn and an extensive research base on method effectiveness. More work remain to be done to explore the efficacy of flipped classroom in engaging students in their learning.

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APPENDIX A

For each of the question posed, a short paragraph is provided to provide the brief explanation of the intent of the question, so that the student co-participant clearly understand what is being asked of them. When appropriate, selected PowerPoint slides or sections of a learning task is provided for greater clarity.

Questionnaire 1

- **Lesson Preparation** - Have the learning guides been useful in planning your learning of the topics in each session? If yes, please explain how, with specific example(s) if possible. If no, identify why not for you.

- **Learning Objectives** - Has the use of a checklist (mid-point or end of lesson) helped you to keep track of your learning of the lesson objectives? If yes, please explain how you made use of the checklist provided. If no, identify why this was not useful for you.

- **Advanced Graphic Organizer** - Was the above diagram helpful for you in keeping track of the progress on the module? If yes, please explain how this helped your learning. If no, identify why not for you.

- **Self-Evaluation using Socrative** - Did you find the questions posed in Socrative useful in helping you to check your understand of the key content in the one component of this topic? If yes, explain how this was useful to you. If not, identify why not for you.

- **Activating Prior Knowledge** - Was the information curated for Bhopal useful in making this a good learning experience for you (e.g., made the learning more interesting/engaging; helped you to answer the questions posed in class)? If yes, explain how. If no, explain why not.

- **In-Class Collaboration using Google Doc** - Did you find such a collaborative approach (such as discussion in groups) more interesting/engaging learning experience than when the lecturer poses a question and ‘nominates’ a student to answer? If yes, what made this more interesting/engaging for you? If no, explain why not.

- **Transfer of Knowledge** - Are you able to use your understanding on inherently safer design strategies (from Socrative, Bhopal) and apply them in the case of Piper Alpha? If yes, what helped specifically? If not, what was confusing for you?

- **Feedback** - Have your received sufficient and useful feedback on your learning so far in this module? Identify specifically what has been most useful and why. Also, what has been least useful (or not provided) in terms of feedback support?

- **Overall Learning Experience** - Explain your learning experience thus far, as well as identifying any topic you found particularly difficult; and offer some specific suggestions (citing the topics if possible) to make the lesson more interesting.
Questionnaire 2

- **Collaborative Learning** - Were you able to collaborate effectively with your team members and build a sound understanding of ATU? Please explain your answer with reasons.

- **Prior Knowledge of Topics** - Did revisiting the DPP help you to better understand how LOPA concepts can be applied in the real world context? If yes, explain how this helped you. If no, what made this difficult for you?

- **Connecting Prior Knowledge to New Knowledge: Manageable Chunks** - Did the activities provided about ATU help you to understand this content better? Explain your answer, identifying what worked best (and least - if this was the case for you) and why.

- **Relevance of Learning** - Did this activity add realism to your learning and help you to better understand the concepts covered in Pressure Relief System? If yes explain what made this helpful for you. If not, identify what you found not useful.

- **Connecting Prior Knowledge to New Knowledge: Transfer of Learning** - Are there adequate exercises on the topic of pressure relief system for you to apply knowledge learnt in earlier exercises to the present ones? Were some more useful than others – if yes, identify which one’s were most useful and what made them useful for your learning.

- **Scaffolding and Deliberate Practice** - Did the Mock Assignment and Peer Marking with Rubrics help you gain a better understanding of this topic area? What was most useful and why, and what was least useful and why?

- **Use of Real-World Examples (intrinsic Motivation)** - Did the examples and activities make this part of the lesson more interesting and engaging for you? Please explain and illustrate your answer.

- **Critical Thinking (Systems Thinking)** - Do you feel that you understand systems thinking from the activities provided? Explain your answer with reasons.

- **Overall Learning Experience: Learning on Your Own** - Explain if these approach had been useful to you in promoting your own learning. If yes, explain how it had helped you. If no, explain why not.
APPENDIX B

As part of the institution’s quality assurance framework, at the end of each semester students are required to provide feedback for the modules they studied and the teaching effectiveness of the lecturer(s) delivering the module. Ratings are given on a Likert Scale of 1 to 5, with “1” being Strongly Disagree, and “5” being “Strongly Agree”.

Questions for Module Feedback

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Additional questions on tutorials and workshops

| Q10                  | The tutorials were relevant to the aims of the module. |
| Q11                  | The tutorials were well taught. |
| Q12                  | The tutorials extended my understanding of the subject matter. |
| Q13                  | The workshops were relevant to the aims of the module. |
| Q14                  | The workshops offered sufficient opportunity to improve my practice of the subject matter. |
| Q15                  | The workshops extended my understanding of the subject matter. |

Questions for Teaching Feedback

| Q1                  | The lecturer organises the lessons well. |
| Q2                  | The lecturer explains and illustrates lessons clearly and makes them easy for me to understand. |
| Q3                  | I feel the lecturer knows the subject matter well. |
| Q4                  | The lecturer keeps the classroom environment positive for learning (e.g. does not allow sleeping, using the mobile phone, talking unnecessarily, etc.). |
| Q5                  | I feel the lecturer is concerned for my learning (e.g. approachable, check our understanding). |
AN INTRODUCTORY COURSE WITH A HUMANITARIAN ENGINEERING CONTEXT

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ABSTRACT

The Engineers Without Borders (EWB) Design Challenge is an excellent example of how universities from across the globe allow students to engage with humanitarian engineering. Massey University has been utilising the EWB Design Challenge as a framework to introduce engineering practice to first year students, and this has led to our teams winning multiple regional and international prizes. This article shares our experience of the design and teaching of this first year course and provides engineering educators with a successful example of how students learn about engineering practice in product, process, and system building, as well as their personal and interpersonal skills. We highlight how, by using a humanitarian engineering context, we embed CDIO thinking. Our case study illustrates how we project manage this process using Stage-Gate™ (Cooper, 2008); support students to conduct reflective practice by using logbooks (Osgood, 2013); include practising engineers as consultants; and provide detailed assessment guidelines and rubric examples to guide students through the myriad challenges during engineering practice. This case study shows that the implementation of the EWB Design Challenge has been successful in providing a useful framework to introduce engineering practice. It is particularly effective in exposing students to a number of ethically driven social competencies required for the global engineer. It is hoped that by sharing our experience of operating this course that engineering faculty may take on-board some of our learning and assessment practices to improve the offering of an introductory design project at their institution.

KEYWORDS

Humanitarian engineering, project-based learning, CDIO Standards 4 and 8.

INTRODUCTION

Over the years a focus on research and specialisation has led to the engineering curriculum becoming filled with theoretical content, leaving little room for the practical application of theory. Research has clearly pointed to the importance of developing the practical engineering skills of problem solving, analysis, systems thinking and innovation (Shekar, 2015). The CDIO (Conceive, Design, Implement and Operate) framework provided guidance to re-design the engineering undergraduate curriculum at Massey University, and include more practical content alongside the theoretical courses. The CDIO model refers to the stages of Conceiving, Designing, Implementing and Operating a new solution that addresses
complex engineering problems. The “Conceive” stage includes defining customer needs; considering technology and regulations; and developing concepts, techniques and business plans. “Design” covers creation of the plans, drawings and algorithms that describe what will be implemented. “Implement” refers to the transformation of the design into a product, including its manufacturing, testing and validation. “Operate” considers how the implemented product will deliver the intended value, including maintaining, evolving and retiring the system (http://www.cdio.org/).

There are global challenges facing the world with regard to accessible clean water, shelter, waste disposal, health and wellbeing. The United Nations’ Millennium Development goals and the current Sustainable Development agenda have identified these and other areas for improvement with specific reference to remote rural communities and urban areas in developing countries (www.undp.org). Previous papers (Shekar, 2015; Goodyer and Anderson, 2011; Gustafsson et al., 2002) as well as recommendations by professional engineering boards have highlighted the need to educate students to address these global challenges and fix the gaps in practical engineering education. Practising engineers, our alumni and Advisory Board members informed us of the importance of good communication skills, team working and problem solving abilities. Students must be prepared to work on technical and non-technical areas as many of these real world problems are complex and interrelated. They must learn to work in teams, make decisions, solve problems and create innovative solutions. In the future there will be more demand for engineers who can interact with people from different disciplines such as supply chain, marketing, social sciences and similar, and have appreciation of inter-disciplinary solutions. This paper presents our first year course, Engineering Practice I: Global Perspectives, which is based on the CDIO learning skills (Table 1). It outlines the structure, assessments and rubrics that are used, so that other educators can adopt some of these successful methods. The key principles of CDIO learning are shown in Table 1, along with their application in our first year course.

Table 1. CDIO Learning Skills and Application in the Global Perspectives Course

<table>
<thead>
<tr>
<th>CDIO Learning Skills</th>
<th>Application in Global Perspectives Course</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduce a framework for engineering fundamentals and practice.</td>
<td>The EWB Design Challenge is an excellent way to introduce the CDIO method with a focus on a socio-cultural context.</td>
</tr>
<tr>
<td>Build personal and interpersonal skills.</td>
<td>Teams of three or four students work together from understanding the brief to finding the best solution.</td>
</tr>
<tr>
<td>Communication skills</td>
<td>Written reports, referencing styles, team meetings, progress meetings with staff, exhibition display and presentation.</td>
</tr>
<tr>
<td>Professional skills</td>
<td>Project management, ethics, appropriateness to context, safety and hazard assessments, sustainability and environment protection.</td>
</tr>
</tbody>
</table>

**HUMANITARIAN ENGINEERING CONTEXT OF THE COURSE**

The Year One first semester course “Engineering Practice 1: Global Perspectives” is based on a humanitarian development theme. It has been run in conjunction with Engineers Without Borders (EWB Australia), who provide us with the background, needs and problems facing people in under-resourced communities (http://www.ewbchallenge.org/). Each year EWB selects a different context for the challenge, e.g. villages in Nepal, Vietnam, East Timor,
Cambodia or Zambia. They also provide the design challenges that range from improving housing, water safety, waste management, providing better transportation systems; and other urgent needs of the community. The project thus presents challenges faced by people in communities in other parts of the world for the students to solve. From the EWB Design Briefs students are expected to identify an area for potential improvement and to develop a solution that solves problems faced by, and provides benefits to the community, with an appreciation of the community’s culture, economics, and materials availability in mind. The solutions should enhance their quality of life, make daily tasks easier and help make their lives healthier and safer. Students are taught that the needs of these communities can be quite different to people living in the Western world. These needs are generally more basic in nature, and students must research the context, community, available resources and current situation thoroughly.

STRUCTURE OF THE COURSE

This first year project-based course is common to all of the engineering majors: Electronics, Mechatronics, Innovation Management and Chemical & Bioprocess Engineering. The students are placed in teams of four by staff, who intentionally balance the mix of majors, student backgrounds (domestic or international students) and gender. This course introduces students to engineering practice (CDIO Standard 4) and active learning (CDIO Standard 8), and is based on working through a project that is based on a humanitarian context. The course project is structured to follow four main stages and has gates at the end of each stage, as per Cooper's Stage-Gate™ model (Cooper, 2008). This is introduced as the Engineering Method. The gates are check points to ensure students are maintaining progress.

The stages of the project are:

1. Problem Definition; focuses on defining the problem (weeks 1 to 4 approximately).
2. Design; develops the project requirements, designs potential solutions and selects one design solution to proceed with (weeks 5-6).
3. Evaluation; allows for detailing and evaluation of the selected design solution against the project objectives and community’s requirements (weeks 7-10).
4. Implementation; this includes having a viable implementation plan (including maintenance), and its communication. The students’ solution could be a product, process or system that fits the context. (weeks 11 and 12).

LEARNING OUTCOMES

1. Identify and solve a contextually complex engineering problem using a systems thinking approach.
2. Explain an engineering system, its behaviour, its elements (including materials) and its interactions.
3. Apply the basic inputs and processes required for project management.
4. Define the key elements of the design process, including safe practice.
5. Reflect on own professional practice using required strategies and modes.
6. Communicate clearly and concisely using appropriate styles in a range of academic and professional settings.
The students follow the stages of CDIO (Conceive, Design, Implement and Operate) during the course. Table 2 shows how we have aligned the conceiving, designing, implementing, and operating of solutions to the humanitarian engineering project activities. Students meet with their allocated staff supervisor on their project day each week. The course is supported by online resources via an internal Moodle-based website named ‘Stream’. Stream provides an outline of the course, the five assignments and related rubrics. It also includes an activities schedule for the project weekday – this has guided workshops in the mornings and team-project work in the afternoons. During the guided workshops, the lecturers introduce concepts and methods and encourage students to apply them in their projects. These sessions are not long, formal lectures, but are short, informative, coaching sessions, followed by staff moving around the class to observe how students apply the methods. Students are asked a number of questions during these sessions to ensure they understand what is expected of them, and to make them think about their decisions and to justify them.

Table 2. CDIO and Project Activities

<table>
<thead>
<tr>
<th>C-D-I-O</th>
<th>Key Project Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conceive</td>
<td>Research all relevant aspects of the context and user needs. Clearly define the problem you are addressing and the desired outcome. Identify all relevant constraints that might impact the successful application of your final solution.</td>
</tr>
<tr>
<td>Design</td>
<td>Generate a list of possible solutions – do not settle for the first solution you come up with. Evaluate your potential solutions against the criteria for success.</td>
</tr>
<tr>
<td>Implement</td>
<td>Develop your final solution in a planned way so as to ensure it meets the needs of the users in the best possible way.</td>
</tr>
<tr>
<td>Operate</td>
<td>Prepare a final report for EWB that clearly describes the solution and its benefits, how it will be implemented and how it will be maintained.</td>
</tr>
</tbody>
</table>

During project activity and assessment, staff look for:

1. Clear and objective decision-making based on sound and appropriate research (the context, appropriate technologies, applications in other locations and so on).
2. Professionalism in all aspects of the project – communication, timeliness, planning, ethics, teamwork.
3. A well-developed, feasible, solution that is based on sound research and decision-making.
4. Justification of the appropriateness of the solution to meet the outcome, and
5. A final report with a concise summary of their final solution, how it was developed, including any recommendations.

ASSESSMENTS

There are five assessments that include a range of methods: Research, Team Discussions, Reflective Writing, a Written Report, and a Visual Display. The assessments cover both individual and team evaluations (Table 3). The recommended textbook for the course is “Engineering Your Future” by Dowling et al. (2016). Students are expected to read specific chapters or sections relating to concepts that are taught during the week and apply the concepts to their problem. External judges are invited to assess the exhibition and hear directly from the students and ask questions about their solutions. The students also have
the opportunity to see and learn from the solutions created by other teams. They come to realize and appreciate in tangible form how there can be different solutions to the same problem. An example of project assessment, an abridged version of the rubric for the Design Report, is given in Appendix A. In particular, it shows how we assess the student’s considerations of environmental, social and economic impact, and benefits of their design. The course is delivered on two campuses simultaneously by different staff. Assessments are moderated across campus through constant communication between staff.

### Table 3. Course Assessments

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Learning outcomes assessed</th>
<th>Individual Assessment</th>
<th>Group Assessment</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Literature Review</td>
<td>1,2,4,6</td>
<td>10%</td>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>2 Design Project Report</td>
<td>1,2,3,4,6</td>
<td></td>
<td>35%</td>
<td>25%</td>
</tr>
<tr>
<td>3 Individual Portfolio</td>
<td>4,5,6</td>
<td>15%</td>
<td></td>
<td>15%</td>
</tr>
<tr>
<td>4 Test (Safety)</td>
<td>2,4</td>
<td></td>
<td>15%</td>
<td>15%</td>
</tr>
<tr>
<td>5 Exhibition</td>
<td>1,2,4,5,6</td>
<td>10%</td>
<td>15%</td>
<td>25%</td>
</tr>
</tbody>
</table>

The Literature Review is used to communicate how the problem is explored. The Design Report communicates the entire project. The Portfolio shows the professionalism of the student and includes their logbook and an interview. The Test is a bridge-build performed by the students and is used to emphasise safe practice in engineering. The Exhibition communicates the entire project and its solution using verbal, visual and prototype forms.

The solutions need to be simple in order to fit the context, meet environmental constraints (in terms of being robust to withstand weather conditions, frequency of usage) and resources available. This suits a first-year course as the students at this stage do not have advanced technical knowledge, and are able to apply some of the basic physical principles they learn. Students also realize what they do not know and recognise how some of that advanced knowledge can be useful to learn in the future. Hence they are encouraged to speak to experts in their particular project area. Expert consultants are also invited to meet with project teams on two separate afternoons during project-day.

### TYPICAL PROJECT EXAMPLES

Student projects range from rainwater harvesting to affordable transportation of crops; from water filtration to improved construction materials for houses or roofs. The students consider the ethical, socio-cultural and economic aspects of their solution. For example, for a project that involved transport of crops from a farm to markets, students researched and determined that it was mostly women who carried out this task, that they generally do not ride bicycles and are not comfortable doing so. Hence a simple hand-cart version was developed that was light, easy to manoeuvre and made of natural materials that are easy to access. Creating affordable solutions means that the materials must be of low cost and easily available in these villages. Students are taught how to carry out a hazard and safety assessment of their design in order to ensure that it does not pose a risk to users, and also during the build and maintenance phases.
STUDENT REFLECTIONS IN LOGBOOKS

Students are required to keep individual logbooks to document progress in their projects. Information entered in the logbooks includes: information gathering and search strategy, meeting minutes, rough sketches of their ideas, a glossary of new terms they encounter during the course, etc. The logbooks are checked weekly by the team’s supervisor for entries under such areas as design sketches, team meeting action points, glossary terms and progress notes. Student feedback reveals that they are motivated to learn in a real-world project environment and enjoy the practical sessions. Student engagement is shown with some teams putting in more effort and many extra hours outside the regular timetabled hours. They also learn about the wider role of engineers and how they can apply their theoretical knowledge to solve real-world problems. We teach students to discuss issues with their group and sign a team contract at the start of the course, based on their expectations and how they would manage their team during the project. We found that this helps them think about team-work, and we get them to refer back to it if team issues arise.

Student Comments on Information Gathering

“It was interesting to learn about people whose lives are so different from ours”.
“At first it was difficult to think about a place that is so far from us, but after doing research we gained more direction and ideas about potential solutions”.
“We learnt that just a Google search was not enough for research about the community, and that we had to connect with people from the community via the EWB website or with local representatives”.

Student Comments on Teamwork

“Dividing the tasks was important in order to make progress”.
“There was a lot of information to research so it was good to have four in our team”.
“It was difficult because the rest of the team were happy with a C and did not put in the effort that I expected. One student was ill and I had to take on his work at the last minute, which put extra stress on me”.
“Teamwork for me was not as good as I expected at the start. There were several breaches of the team contract, and I ended up writing most of the report”.

COURSE EVALUATION

An online course evaluation was gathered from the class relating to a number of areas at the end of the 2016 semester (administered anonymously and automatically by the Massey University system). In 2016 the four-year old course was revised due to staff changes.

The Online Survey Questions are given below:

1. Overall, I was satisfied with the quality of the learning experience in this paper
2. This paper helped develop my thinking skills
3. The content of the paper was structured in a way that assisted my learning
4. It was clear how the parts of this paper contributed to the learning outcomes
5. The support materials were useful to my learning
6. Assessment requirements were clear

7. My marked assessment was returned within the turnaround time stated in the paper outline
8. Feedback on my work helped me learn
9. The workload for this paper was reasonable
10. The online learning environment enhanced my learning

The scale of responses is: Strongly Disagree, Disagree, Tend to disagree, Tend to agree, Agree and Strongly Agree. Students can comments after each question, and enter overall comments.

**Results and Discussion**

The results are presented graphically. There are two sets of results as the course is delivered on two campuses by staff located at each campus. Twenty-five students out of sixty-seven at Campus 1 answered all ten questions, and their responses are shown in Figure 1. Twenty-one students out of forty-eight at Campus 2 answered all ten questions and their responses are shown in Figure 2. The survey is analysed qualitatively due to the low number of participants.

The overall satisfaction (Q1) was high, 88% on Campus 1 and 64% on Campus 2. The workload, online support material and guidance given by staff were well received. Some students felt they needed more guidance relating to expectations in each assessment (Q6) – this is attributed to several factors. Firstly, assessment requirements were changed during the semester to ensure formative assessment of the design report occurred, and there were also different expectations of staff assessing the material. Cross-campus moderation assists with the second issue but this is not visible to students. To address this, it was decided to show previous years’ student example assignments. There was some dissatisfaction with the study materials (Q5 – 44% on Campus 1 and 42% on Campus 2.), mainly relating to the recommended textbook Dowling et al (2016) as the students struggled with the focus of the textbook on largely infrastructure projects.
Figure 1. Campus 1 Responses to Survey Questions

The course was considered by students to have developed their thinking skills (Q2), which is considered important as “Systems Thinking” is emphasised throughout the project. The
workload (Q9), online support material (Q10) and guidance given by staff (Q8) were well received. There are some challenges in getting students to connect course information from across the theory courses and apply it to the project courses. This was addressed by using subject experts during student team-time to encourage them to apply theoretical and physical principles. We continue to review the project courses to ensure their alignment with the CDIO framework for knowledge and skills development.

The results show that the students at Campus 2 were more likely to disagree with a statement than those on Campus 1. It is not known why these differences have occurred, though differences are noted in other engineering courses when compared across the campuses. The academic results of each cohort of students were similar, and it is likely some differences are due to subject delivery by different staff in each location. The required capability of staff involved in Project-based learning is to be investigated in a wider study.

CONCLUSIONS

The CDIO syllabus and standards provided the building blocks for design engineering practice courses that combine theory with application. They served as a guideline for course design based on the key knowledge, skills and attitudes required for engineering graduates. This paper shares our course on humanitarian engineering practice that is based on the CDIO framework implementation. The course is structured as four stages; Stage 1 reviews the literature and background information to the problem. Stage 2 involves idea generation and decision making. Stage 3 evaluates a chosen solution that is selected from a range of potential options. The final stage includes an exhibition, a visual display of the prototype and a written report. At this stage students also submit their individual logbooks and self and peer assessments.

The student project examples highlight the application of CDIO competencies, including ethically and socially relevant approaches to problem solving, within a resource-constrained context. A range of assessment methods were used throughout the course and an example rubric is shown in Appendix A. The course evaluations and student comments were mostly positive but also show the variation that occurs in student opinion when teaching the same course on different campuses. The paper has demonstrated how we have integrated and implemented the CDIO framework and Standards 4 (introductory engineering) and 8 (active learning) through social innovation projects in the first year.

ACKNOWLEDGEMENT

The authors wish to thank EWB for their partnership and the staff and students involved in the course.
REFERENCES


BIOGRAPHICAL INFORMATION

Aruna Shekar, Ph. D. is a Senior Lecturer in Product Development at Massey University's School of Engineering and Advanced Technology, Auckland, New Zealand. She has coordinated the first year Humanitarian Engineering course in conjunction with Engineers Without Borders (EWB) for four years, and every year her students have won National and International awards. She has been nominated in 2015 and 2016 as ‘Lecturer of the Year’ by students in a recent initiative. Aruna led the curriculum design and delivery for a compressed first year engineering ‘Accelerate Programme’, which included project-based learning. She has presented at National and International Conferences. Her educational interests are in developing skills in user-oriented innovation with a humanitarian engineering focus.

Dr Shekar established the New Zealand Affiliate of the global Product Development & Management Association (PDMA) along with a colleague, and continues to be on the Board. She currently holds the position of Vice-President for Asia-Pacific with PDMA (USA).

Mark Tunnicliffe, Ph. D. is a Senior Lecturer in Product Development and Innovation at Massey University's School of Engineering and Advanced Technology, Palmerston North, New Zealand. He has taught and supervised the first year Humanitarian Engineering course in conjunction with Engineers Without Borders (EWB) for three years. He has also coordinated the second year project course, “Product Development” for two years. His education interests are in developing young engineers through project-based learning with skills relevant to industry. He joined Massey University after 18 years working as a Research and Development Engineer at a medium-sized New Zealand manufacturing company.

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**APPENDIX A**

<table>
<thead>
<tr>
<th>Aim and Review Criteria</th>
<th>Mark Allocation</th>
<th>Mark</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PROBLEM DEFINITION</strong></td>
<td>&lt;10</td>
<td>10-12</td>
</tr>
<tr>
<td>(20 marks)</td>
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<td></td>
</tr>
<tr>
<td>Removed details here to save space (can be provided if required)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>DESIGN</strong></td>
<td>&lt;7.5</td>
<td>7.5-9</td>
</tr>
<tr>
<td>(20 marks)</td>
<td></td>
<td></td>
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<tr>
<td>Removed details here to save space (can be provided if required)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>WRITING STYLE AND FORMAT</strong></td>
<td>&lt;3.5</td>
<td>3.5-4.5</td>
</tr>
<tr>
<td>1st iteration</td>
<td></td>
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<td>(7.5 marks)</td>
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<td></td>
</tr>
<tr>
<td><strong>Evaluation</strong></td>
<td>&lt;17.5</td>
<td>17.5-21</td>
</tr>
<tr>
<td>(30 Marks)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The final design solution proposed is technically sound</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Students evaluate the final design with respect to environmental, social, and economic costs, impacts and benefits</td>
<td>No consideration for the design's environmental, social, and economic context.</td>
<td>Good description of the design's environmental, social, and economic context.</td>
</tr>
<tr>
<td>Students use an ethical framework to evaluate the final design</td>
<td>No consideration of the use of an ethical framework to evaluate the design.</td>
<td>Good description of the use of an ethical framework to evaluate the design.</td>
</tr>
<tr>
<td>Students evaluate the final design, its construction and use with respect to safety</td>
<td>No description of potential safety hazards and their minimisation to evaluate the design.</td>
<td>Good description of potential safety hazards and their minimisation, using appropriate techniques to fully justify your evaluation.</td>
</tr>
<tr>
<td><strong>IMPLEMENTATION</strong></td>
<td>&lt;7.5</td>
<td>7.5-9</td>
</tr>
<tr>
<td>(15 marks)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Removed details here to save space (can be provided if required)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>WRITING STYLE AND FORMAT</strong></td>
<td>&lt;3.5</td>
<td>3.5-4.5</td>
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<tr>
<td>Final Iteration</td>
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<td>(7.5 marks)</td>
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TEN YEARS OF CDIO EXPERIENCES LINKED TO TOY DESIGN

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Juan de Juanes Márquez Sevillano
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ABSTRACT

Toys are deeply rooted to the natural learning process of children, as they investigate for themselves learning cause effect relationships and the relevance of boundary conditions, and to the development of their personality and social skills, as they observe and interact with other children and adults when playing. Learning through play, promoted by pioneers as Montessori, Piaget and Steiner, is among the most powerful teaching-learning strategies and currently forms part of high-quality curricula worldwide, mainly from early childhood to high school. Our experience shows that it can be also successfully applied to higher Education and that living through the complete engineering design process of real toys, following the CDIO scheme, is an excellent strategy for making engineering students face real industrial challenges while they design, dream, play and learn.

A decade ago we started to set the foundations towards the European Area of Higher Education, which should promote active learning in contexts more linked to professional practice. To this end, several courses in our Industrial Engineering Degree began to incorporate project-based learning activities, although initially with a more limited scope than that of the integral CDIO approach, as fundamental part of the teaching-learning process. In our course on “Design and manufacturing with polymers” we opted for including capstone collaborative projects linked to designing real plastic products and the related mass-production tools. We decide to propose students to design toys and the related injection molds, which constitute great examples of complex engineering systems, using state-of-the-art industrial methodologies and resources. The topic of “toy design” has proven to be motivating for students and teachers and has helped us to re-invent the course in every edition. Our course has served as application example of the benefits of student-centered teaching-learning strategies at ETSII-UPM along the implementation of the “Bologna process”, which has culminated with the beginning of the Master's Degree in Industrial Engineering, a programme that devotes more than a 20% of activities to project-based learning following the CDIO standards, in which the detailed course continues as part of the Mechanical Engineering major. Here we present a summary of the course evolution during the last decade and analyze its main teaching-learning results.

To our knowledge, this “complete toy design experience” constitutes one of the first integral applications of the CDIO methodology to the field of Industrial Engineering in our country and stands out for ten years of continuous improvements. Around 500 students have taken part...
in these projects from our “Design and manufacturing with polymers” course at ETSII-UPM and more than 200 real toys, together with the related injection molding mass-production tools, have been designed during the last ten years. The most outstanding designs have been manufactured and tested every year for letting students live the whole CDIO cycle.

KEYWORDS

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

INTRODUCTION

Student motivation and active engagement to their own learning process is a key success factor in Higher Education, especially in Science and Engineering paths, as recognized and highlighted in several studies, reports and declarations, such as the Bologna Declaration and the subsequent related declarations from Prague, Berlin, Bergen, London, Leuven and Budapest-Vienna, aimed at the implementation of the European Higher Education Area (EHEA). Making students drivers of change is perhaps the most effective part of a global strategy, for the promotion of professional skills in Engineering Education (Shuman, et al. 2005, Díaz Lantada, et al. 2013). Problem- or project-based learning (typically PBL) methodologies clearly tend to motivate students to participate and become involved in their own learning process and is an excellent way of analysing whether students have acquired the basic concepts taught in the theory classes and if they are capable of applying them in real situations. These PBL experiences have proven to be effective in primary, secondary and university education and in scientific-technological, bio-sanitary, humanistic and artistic contexts. In consequence, most technical universities, before awarding the engineering degree, almost always include the standard final degree project as part of the studies, which, basically, is a PBL learning experience. In direct connection with the promotion of project-based learning methodologies worldwide, even though its holistic approach to engineering education development goes far beyond project-based learning, the CDIO™ Initiative (www.cdio.org) is probably the most ambitious approach. The CDIO™ Initiative is focused on the establishment of an innovative educational framework for producing the engineers of the future, by means of providing students with an education stressing engineering fundamentals by means of “Conceiving - Designing - Implementing – Operating” (CDIO) real-world systems, processes and products (Crawley, et al. 2007). Throughout the world, CDIO Initiative collaborators are adopting CDIO as the framework of their curricular planning and outcome-based assessment. CDIO also promotes collaboration and sharing of good practices among engineering educational institutions worldwide.

Project-based learning following the CDIO approach can be also linked to “learning through play” methodologies, in which toys may play a fundamental role. In fact, toys are deeply rooted to the natural learning process of children, as they investigate for themselves learning cause effect relationships and the relevance of boundary conditions, and to the development of their personality and social skills, as they observe and interact with other children and adults when playing. Learning through play, promoted by pioneers as Montessori, Piaget and Steiner (Davies, et al. 2002), is among the most powerful teaching-learning strategies and currently forms part of high-quality curricula worldwide, mainly from early childhood to high school. Our experience shows that it can be also successfully applied to higher Education and that living through the complete engineering design process of real toys, following the
CDIO scheme, is an excellent strategy for making engineering students face real industrial challenges while they design, dream, play and learn.

A decade ago we started to set the foundations towards the European Area of Higher Education, which should promote active learning in contexts more linked to professional practice. To this end, several courses in our Industrial Engineering Degree began to incorporate project-based learning activities, although initially with a more limited scope than that of the integral CDIO approach, as fundamental part of the teaching-learning process. In our course on “Design and manufacturing with polymers” we opted for including capstone collaborative projects linked to designing real plastic products and the related mass-production tools. We decide to propose students to design toys and the related injection molds, which constitute great examples of complex engineering systems, using state-of-the-art industrial methodologies and resources.

The topic of “toy design” has proven to be motivating for students and teachers and has helped us to re-invent the course in every edition. Our course has served as application example of the benefits of student-centered teaching-learning strategies at ETSII-UPM along the implementation of the “Bologna process”, which has culminated with the beginning of the Master’s Degree in Industrial Engineering, a programme that devotes more than a 20% of activities to project-based learning following the CDIO standards, in which the detailed course continues as part of the Mechanical Engineering major. In addition, the subject served as example for the subsequent implementation of the “Industriales Ingenia” Initiative, previously presented in CDIO congresses, that played a relevant role in the incorporation of ETSII-UPM to the International CDIO Initiative (Díaz Lantada, et al. 2014, Lumbreras, et al. 2015). Here we present a summary of the course evolution during the last decade and analyze its main teaching-learning results.

To our knowledge, this “complete toy design experience” constitutes one of the first integral applications of the CDIO methodology to the field of Industrial Engineering in our country and stands out for ten years of continuous improvements. Around 500 students have taken part in these projects from our “Design and manufacturing with polymers” course at ETSII-UPM and more than 200 real toys, together with the related injection molding mass-production tools, have been designed during the last ten years. The most outstanding designs have been manufactured and tested every year as a way of letting students live the whole CDIO cycle.

THE “DESIGN AND MANUFACTURING WITH POLYMERS” COURSE

Learning objectives and desired outcomes

Our main aim, when planning the course on “Design and manufacturing with polymers”, was to make students aware of the relevant connections between geometries, materials and manufacturing processes in real industrial design projects. Such connections are even more essential if the design projects are linked to using polymeric parts and aimed at mass-production by means of injection molding. In these projects, very special considerations have to be taken into account for an optimal in service performance of the polymeric parts, but also for an adequate cost- and eco-efficient mass-production. Therefore we planned the course for explaining such interdependent relations of the triad “geometry-material-process” and with the intention of making our students good designers of parts and of related manufacturing tools for their potential professional development in the plastics industry. We
wanted them to understand these issues by means of real cases of study, adapted from previous experiences in research, development and innovation tasks performed in collaboration with industrial partners by our research groups at UPM. In addition, we wanted to introduce common theoretical and practical aspects of polymeric materials, of polymeric part design and of polymers processing, especially focusing on injection molding and on the design of molds and related injection molding tools. Since the beginning we understood that it would be beneficial for the students to acquire experience with design and simulation resources typically used in this industry (computer-aided design resources, finite element modeling tools, computer-aided manufacturing systems…), as the sector is quite relevant in our country and as companies usually pay attention to hands-on experience with specific software tools, for the incorporation of junior engineers. We thought that letting students live through complete polymeric product development experiences would allow them to apply the acquired knowledge in a practical way and would make them work in an almost professional context, very similar to what they could eventually live in an industrial environment. It proved a very enriching experience, both for students and teachers, as detailed further on.

Structure of contents, teaching methodology and historical perspective

According to the aforementioned learning objectives and outcomes, the course is divided in two inter-related parts, one linked to designing and modeling the performance of polymeric parts and one linked to designing and modeling the molds and tools required for their mass-production. The main contents of these two fundamental blocks are listed below (Table 1):

<table>
<thead>
<tr>
<th>Block I. Polymeric part design</th>
<th>Block II. Injection mold design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamentals of polymeric materials</td>
<td>Fundamentals of polymers processing</td>
</tr>
<tr>
<td>Fundamentals of polymeric part design</td>
<td>Fundamentals of injection molding</td>
</tr>
<tr>
<td>Joining methods and related design aspects</td>
<td>Mold design issues: Mold structures</td>
</tr>
<tr>
<td>Computer-aided design of polymeric parts</td>
<td>Mold design issues: Mechanical issues</td>
</tr>
<tr>
<td>Finite-element modeling of polymeric parts</td>
<td>Mold design issues: Thermal issues</td>
</tr>
<tr>
<td>Visco-elasticity and performance of polymers</td>
<td>Simulation of injection molding processes</td>
</tr>
<tr>
<td>Rapid prototyping by additive manufacturing</td>
<td>In silico assessment of final part quality</td>
</tr>
</tbody>
</table>

Regarding teaching-learning methodology, as previously advanced, we opt for project-based learning following the CDIO approach. Students work in groups typically of three or four students and develop a plastic product, designing the different parts, selecting the adequate polymeric materials, defining joining methods, optimizing the geometries towards mass-production, defining the mass production tools (molds and components) and in silico assessing final part quality. The results from the complete projects account for a 70% of the global mark of the students enrolled in a group. Individual evaluation is promoted by means of additional personal home-works (linked to analyzing plastic parts), which account for the remaining 30% of the global mark.

The subject was implemented in parallel to the adaptation of our ETSII–UPM to the EU Area of Higher Education (see Figure 1). In the first version (2005-2014) the course was designed as a 4.5ECTS-course, which implied between 112 and 135 hours of students' personal work; in the second re-designed version (2015-future) it is a 3ECTS-course, which implies between 75 and 90 hours of students' personal work. The re-design has supposed an increased use of in-class modeling tools and e-learning resources for more-efficient teaching practice and a
reduction of the expected devoted hours to the design projects (from around 90 to around 60 hours). In following sections we will discuss this evolution and its consequences.

Figure 1. Evolution and implementation of CDIO activities at ETSI Industriales – UPM and the two versions of the “Design and manufacturing with polymers” course.

CDIO APPLIED TO “TOY DESIGN” EXPERIENCES

Planning of the experiences

Once the groups are formed, students decide the product they would like to design and gather information on their product and context, analyzing existing solutions together as a prior stage to the design tasks. Along the decade 2005/2006-2015/2016, we proposed “toy design” as main topic for selecting the products. Toys are fun to design but also quite demanding engineering products, if mechanical issues, material selection aspects and optimization strategies for manufacturability are adequately addressed. In addition, toys provide a nice equilibrium between the desired complexity for applying theoretical aspects along the design and feasibility for living a complete CDIO cycle in a one-semester course. In some cases, so as to promote homogeneous boundary conditions to all participant groups, monographic topics have been explored (i.e. “car design”, “plane design” or “toys inspired on the machines of Leonardo”, among others). The result of this initial stage is a list of requisites with the basic information for the project (desired toy to be designed).

From the need to the concept

The teams continue to work on the list of requirements to identify main problems and to choose the best conceptual solutions for each issue, paying attention to manufacturability, time optimization and costs reduction. Drawing sketches and using computer-aided design programs, student groups obtain a pre-design of the components and select among main connecting options. A potential set of materials is also chosen according to the initial estimations of resistance required for the different components.
From the concept to the design

Once the most appropriate solution has been chosen from the different pre-designs, the different parts must be exactly defined. Following the concepts explained in the theory classes, the students use a design approach oriented to manufacture and assembly. In order to verify that the chosen materials are suitable, the initial estimations are further analyzed with the information provided by computer-aided engineering programs, considering the triad “geometry-material-process”.

From the design to the implementation and operation

In our course, implementation and operation are related to the design of molds and to the in silico evaluation of mass-production by injection molding, as the investment required for the manufacture of real molds is beyond our capabilities. The use of injection molding simulation programs is fundamental, in order to check that the choice of materials and injection molding conditions are appropriate, as well as to define: i) an optimum distribution of the cavities in the mold, ii) the adequate material inlets, iii) the filling channels and iv) the eventual cooling system. Molding simulations are carried out in order to choose the optimum (theoretical) injection point or to evaluate times and temperatures obtained when filling the mold and cavities. To promote student motivation, to check ergonomics and aesthetics and to perform limited functional validations, prototypes the best toys are manufactured using additive manufacturing resources.

Assessment of students and projects

Along the projects, the groups of students interact with the professors and present their results, which involves typically a public presentation linked to the concept and design and another linked to the implementation and operation. Final project results constitute a 70% of the global evaluation, as previously mentioned. Technical quality, product viability, creativity, teamwork and communication skills, among other outcomes, are evaluated.

SUMMARY OF RESULTS: A DECADE’S PERSPECTIVE

As brief summary of results, Table 2 includes some figures related to student and teacher success, motivation and implication in the subject, as compared with subjects of the Industrial Engineering Degree before implementing student-centered activities, as a consequence of the adaptation to the European Area of Higher Education. The positive effect of shifting towards CDIO related methodologies can be clearly appreciated. It is necessary to indicate that the benefits affect not only learning and acquisition of outcomes, but also student and teacher motivation and mutual relation in a very special way, which is starting to influence the overall ambience of learning, collaboration and respect present in our novel Master’s Degree in Industrial Engineering, for which the “Design and manufacturing with polymers” course was a pioneer pilot experience. Such positive aspects clearly rely on an important increase of teacher dedication outside the classroom to the CDIO-based subject, but the general impression is that such additional dedication is compensated by the highly satisfactory results. However, this approach requires more resources than more traditional plenary master classes. In any case, as the topics covered can be of special interest for several enterprises, with which we normally collaborate by means of Enterprise-University Chairs, it is possible to search for additional funding and sponsorships. Our intention is to incorporate enterprises from the product design industry into the course, as key players for
proposing complex projects, for implementing student competitions and even for evaluating our students.

To further illustrate students’ results within the course, Figure 2 and 3 provide examples of computer-aided designs, simulations for design optimization and prototypes for design validation; while Figures 4 and 5 show examples of injection mold design towards mass-production, with analyses linked to filling time, part quality assessment and performance of refrigeration system. Main lessons learned, future perspectives and forthcoming challenges are additionally discussed in the following Section.

Table 2. Some figures related to student and teacher motivation and implication in the “Design and manufacturing with polymers” course along a whole decade.

<table>
<thead>
<tr>
<th>Control aspect</th>
<th>In conventional subjects before the promotion of student-centered approaches</th>
<th>In play-based CDIO “Design and manufacturing with polymers” course along a decade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Success ratio</td>
<td>45% – 75%</td>
<td>&gt;95%</td>
</tr>
<tr>
<td>Student attendance to scheduled lessons</td>
<td>35% – 65%</td>
<td>&gt;80%</td>
</tr>
<tr>
<td>Typical number of answers to debate questions</td>
<td>1 – 3</td>
<td>6 – 8</td>
</tr>
<tr>
<td>Typical number of student questions / hour</td>
<td>2 – 5</td>
<td>4 – 6</td>
</tr>
<tr>
<td>Frequency of meetings between the teachers of the same subject</td>
<td>2 / semester</td>
<td>3 / month</td>
</tr>
<tr>
<td>Num. of interactions with students outside the classroom / week</td>
<td>0 – 3</td>
<td>5 – 10</td>
</tr>
<tr>
<td>Resources needed for practical activities</td>
<td>0 – 100 € / student for practical sessions</td>
<td>300 – 500€ / group for prototyping tasks</td>
</tr>
<tr>
<td>Hours devoted by the teachers outside the classroom / class hour</td>
<td>0.5 – 1</td>
<td>3 – 4</td>
</tr>
</tbody>
</table>
Figure 2. Examples from monographic year devoted to toy car design. Computer-aided designs and simulations for design optimization. (Students’ designs).

Figure 3. Examples from monographic year devoted to toy plane design. Computer-aided designs, simulations for design optimization and prototypes. (Students’ designs). Prototype: UPM’s Product Development Laboratory.
Figure 4. Examples of injection mold design towards mass-production. Filling time analysis, part quality assessment, refrigeration system design and mold structure. (Students’ designs).

Figure 5. Mold concept and final computer-aided design of the mold. (Students’ designs).
LESSONS LEARNED AND MAIN FUTURE CHALLENGES

Main lesson for the professors of the course is that implementing courses following this CDIO “play-based” approach is extremely motivating and gratifying for students, whose learning is promoted, but also constitutes a source of continuous learning and improvement for the teachers, who every year live with the students the development of novel engineering products and processes. However, in order to promote quality of results, these courses must be re-invented every year, for instance by changing the topics for projects development or by adjusting the different steps of the methodology. This helps to avoid students’ copying from companions from previous years and to provide them with a feeling of exclusivity and innovation. All this is time-demanding for teachers but enormously enriching.

Computer-aided design and engineering resources

The employment within the course of state-of-the-art computer-aided design and engineering resources, used by professionals in the plastic industry, helps to increase student motivation and to prepare them for their forthcoming professional practice, allowing them to obtain hands-on experience in relevant tools for daily engineering practice, as a complement to the technical knowledge acquired along the course.

“Fab-labs” and 3D printing hubs

Access to prototyping facilities, as a support to the in silico assessment of design viability, is an additional source of motivation for students and can be cost-effective indeed, if only the best designs are manufactured, which promotes healthy competition and enhances results.

e-Platforms for project management and collaborative design

Among future proposals for continued improvement, we believe that the use of e-platforms for promoting collaborative design tasks among the different groups of student may help to tackle more demanding projects and to further promote teamwork skills. If adequately implemented and used, they can help to promote approaches linked to “Engineering Education for all” (Díaz Lantada, 2016).

Collaboration between academia and industry

Regarding additional challenges, we would also like to explore the possibility of transforming the course into a whole-year subject with a larger amount of credits (i.e. 12 ECTS) for letting students live through an even more complete CDIO cycle, in which they could reach the mold manufacture stage and produce series of products to validate the whole approach and check the expected quality. Eventually we could link the design projects with real needs from the local industry, for instance aiming at the complete development of plastic parts for the automotive or aeronautic sectors, in which a polymeric component would be required to fit into a pre-existing assembly of parts of different materials and obtained with different processes. This would provide students with more complex specifications and let them work in an even more real professional environment.
CONCLUSIONS

We have presented a CDIO-based “complete toy design experience” within our course on “Design and manufacturing with polymers” and main results from implementation and evolution along a whole decade at ETSI Industriales – UPM. This experience constitutes one of the first integral applications of the CDIO methodology to the field of Industrial Engineering in our country and stands out its being linked to a “learning through play” approach. Around 500 students have taken part in these course and more than 200 real toys, together with the related injection molding mass-production tools, have been designed during the last ten years. The impact in the professional development of students and in teachers’ perspective about their own professional practice at University is noteworthy. This constitutes one of the longest running CDIO experiences in the field of product design and manufacturing.

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CDIO Standards 2.0: http://www.cdio.org/implementing-cdio/standards/12-cdio-standards
BIOGRAPHICAL INFORMATION

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ADDRESSING INTERGRATED LEARNING THROUGH PROJECT-BASED COURSES – FIVE YEARS OF IMPROVEMENTS

Daniel Einarson, Diana Saplacan

Computer Science, Kristianstad University, Sweden

ABSTRACT

Project-based educational forms are at the core of the CDIO concept, where students should be trained in contexts of complex enough tasks to prepare for the complexity of industry projects. Besides from fulfilling a project in itself, CDIO points out the importance of achieving integrated learning skills, including personal and interpersonal skills (CDIO Syllabus sections 2 and 3), where those are desired to meet the challenges of the working processes.

Projects in education moreover correspond to active learning, where students are encouraged to learn through solving the problems required to fulfill the goals of a project. Being active in the process of completing a project, does not only imply disciplinary training, but also training in achieving generic skills, such as experimentation, knowledge discovery, system thinking, teamwork, and communication. All in all, a conclusion is that student activities in project-based teaching and learning relate to all four sections of the CDIO Syllabus, and hence active learning will here contribute to integrated learning. Thus, activating students in project-based courses should have several positive values.

However, experiences show that one problem in project-based courses is that of activating a major part of a student group. Here, a common pattern is that some students are not contributing enough, resulting in other students covering up for them, or risking the whole project. Therefore, teaching efforts should be put on finding ways to widen the group of active students.

The project-based course Software Engineering 2, at Kristianstad University, Sweden, has undergone several years of improvements in order to, on one hand reduce the number of passive students, and on the other hand increase values of generic skills from the CDIO Syllabus. This paper will present development steps of that course. Methods, where some have been inspired from the Software Engineering industry, will be covered, and results of using those will be provided. A major result is that of increasing values of integrated learning, where this in itself contributes to the core of CDIO.

KEYWORDS

Project-based course, integrated learning experiences, CDIO learning outcomes, ethical aspects, capability-maturity model (CMM), self-awareness, Standards: 5, 7, 8.
INTRODUCTION

Project-based training is especially pointed out by the concept of CDIO, where values of project result is dependent, not only on the fulfilment of the project itself, but also on personal and interpersonal skills. The compound value of students’ performance is therefore an integration of abilities regarding all four sections of the CDIO Syllabus. That is, a project-based course is in itself a fundament for CDIO Standard 7, Integrated Learning Experiences. Furthermore, project-based courses are also examples on active learning forms (CDIO Standard 8), where learning activities concern all the four sections of CDIO Syllabus. That is, active learning has positive effect on achieving integrated learning skills. Project-based courses are valuable approaches to active learning, where a main effort for fulfilling the project lies on the students. The level of student activity may however be negatively influenced by aspects, such as, unclear working process models, and low grade of ambitions, which in turn have negative impact on integrated learning.

The project-based course, Software Engineering 2 (SE2), at the department of Computer Science, Kristianstad University, Sweden, has undergone several changes since 2010, when it started in the current shape. The students shall solve one main task (selected by teachers), where the level of scale and complexity of that task requires groups of about 15 students. The groups are then divided up into sub-groups of about 3 students, where sub-groups solve parts of the main task that eventually are integrated to fulfill the whole of the project. Teachers have here observed the above mentioned problems, and improvements to the course have been done to further develop students’ activities as well as the integrated learning skills of those.

This contribution illuminates on how SE2 has undergone several steps of progressions, to meet and overcome the mentioned problems, with observed positive results. In short: At year 1 (2010) it was observed that students did not understand how to approach the work. To meet this, at the next year the, so called, Capability Maturity Model as a guidance of working was introduced. At year 2, it was observed that groups of students did not contribute enough, which led to introduction year 3, of the Code of Ethics for software engineers. At year 3, it was still observed that some students were not contributing enough, which led to introduction of anonymous student evaluations. At year 4, the traditional lectures were replaced by student active seminars. Finally, at year 5, the seminars format was changed to activate students even further. Moreover, the anonymous evaluations were refined. Thereafter an additional step of repetitive evaluations of generic skills has been introduced, to push the ambition on integrated learning skills at an even higher level.

The aim of this contribution is to give a complete view on progressions made, and to serve as a possible guidance in circumstances of implementing courses such as SE2. Next section will give a more detailed view on the course. Thereafter, course improvement steps will be covered, and conclusions will be provided.

A BRIEF PROJECT OVERVIEW

The course Software Engineering 2 has in its current shape been provided since 2010, where the structure of the project is intended to be complex enough to require up to about 15 students to fulfill the project. The student group as a whole is here divided up into sub-groups of about 3 students per group, putting significant demands on collaboration and communication. Meanwhile, the project task should be technically complex enough to
address challenges outside the core of the rest of the courses’ contents, with the implication that students have to extend their disciplinary skills through own discovery initiatives.

**Project Structure**

The core of the project task is to develop a system with smart house techniques, where the system is to be used by people with functional disabilities. There have been other project tasks too, but for reasons of simplifications, a focus is put on smart house projects. The system interacts with devices, such as lamps, temperature sensors, and radiators. Moreover, the system includes a server, database, and parts for communication. At the front end part, apps at smart phones, and web-based interfaces are used for human-system communication. Figure 1 illustrates this, as also illustrated in (Einarson, 2011).

![System overview of student project.](image)

To be able to fulfill the project as a whole, the student group has to be divided into sub-groups, where those develop their specific part of the system, or project. Typically, as show in Figure 2, (Einarson, 2011), a part may correspond to functionality for devices of the smart house, middleware, or interactive human user controller parts. The group as a whole has a project leader, and a requirements manager. Moreover, each sub-group has one specific sub-group leader.

![Project group structure.](image)
The course is on 15 academic credits, and runs over one semester. The structure of the working process includes several iterative meetings with teachers, where the project is discussed so far. Before those meetings the groups shall upload a number of artefacts that should clearly describe aspects, such as, design, project risks, requirements, supplementary requirements, and more.

**The Project's Correspondence to CDIO**

It can clearly be seen that the project corresponds well to all four sections of the CDIO Syllabus. Therefore, CDIO Standard 7, *Integrated learning experiences*, should be addressed (still, without involvement of stakeholders outside education), and also Standard 8, *Active learning*. The project does furthermore clearly correspond to several points of level 2 of CDIO Syllabus (CDIO Syllabus). For instance, point 2.2 is required since *experimentation, investigation and knowledge discovery* all are needed to approach, and fulfill the project. 2.3 *System thinking* is also clearly addressed. 3.1 *Teamwork* is at the core of the project, as well as 3.2 *Communication*, and international students do furthermore contribute to 3.3 *Communication in foreign language*. Points 4.3, to 4.5, are all obvious (please see more on (CDIO Syllabus) for more on the details), and 4.1 *External, Societal, and Environmental Context*, is addressed from the point of the problem domain, that is, people with functional disabilities. Moreover, seen from perspective of CDIO Syllabus, level 3, there is further correspondence to, e.g., 2.4.1 *Initiative and the Willingness to Make Decisions in the Face of Uncertainty*, 2.4.3 *Creative Thinking*, and 2.4.7 *Time and Resource Management*. Those points are motivated by the fact that the strategies to solve the project should be left to the students themselves. This is a fact that also contributes to finding strategies to meet point 2.4.6 *Lifelong Learning and Educating*, which closely relates to points 2.4.1, and 2.4.3.

**PROGRESSIONS – FIVE YEARS OF IMPROVEMENTS**

For purposes of motivating the project, and preparing for future of students, structures of the course have been inspired by methods and principles from the Software Engineering field as it is established in industry. This relates to the working process at large, as well as on levels of personal attitudes.

**First Year**

The style of the working process was set. An iterative and incremental style was chosen, that lays close to the Rational Unified Process, or rather UPEDU, the Unified Process for Education (UPEDU, 2014), but simplified to exclude much of the extensive work on documents. Please see in (Einarson, 2011) for more on that, and how it is furthermore explained how well the Software Engineering field may influence CDIO-based educational forms.

Even though several of the CDIO Syllabus Learning Outcomes seemed to be met by the course, the teacher (one of the co-authors of this paper) found it hard to see the value of the course, with respect to student results. It seemed to be hard to see the actual individual contributions, and the teacher's assumption was that parts of the student group did not contribute enough. The course evaluation showed that students understood the goal of the project as such, but did not understand the process of getting there, they wanted the teacher to be more clear on that and provide guidance in that direction during the project. That was
also the main point of criticism that the teacher carried to the next year the course was provided.

**Second Year**

The teacher’s conclusion from the first year was that it would be of higher values if students decided about their process more by themselves than if the teacher should do it. To meet this, the concept Capability Maturity Model (CMM), from Software Engineering (Sommerville, 2010), was clearly introduced. The CMM can be explained as a five-level model for development organizations, where each next level corresponds to a higher level of organization maturity. Figure 3, illustrates CMM.

![Diagram of CMM levels]

Figure 3. Levels of the Capability Maturity Model (CMM).

Level 1, corresponds to an ad hoc way of working, which also often is a way that student projects are done. Level 2, corresponds to a defined way of working, typically set by a project manager, and where the development team has to follow this. In the context of the project-based course, SE2, the first year corresponds much to that level. The teacher here instead wanted to simulate level 3 at the course. This means that the process should be defined by the students themselves, resulting in much more effort on learning outcomes, such as, teamwork and communication, attitudes thought and learning, and others.

The result, as presented in (Einarson, 2012), shows that the course through this approach undergone great improvements. Results were clearly better, both when it came to the final project result, and the process of getting there. It could also be shown that values of several learning outcomes were improved.

However, during the process it was clearly shown that sub-groups of students did not contribute, with frustration at student project managers, and risks for project fulfilment, as results. The teacher tried to meet such problems with arguments, such as, ethical behaviour and moral, but had hard to get through. While the course result was generally good, that was the main problem the teacher carried on until next year.
Third Year

In order to reduce the number of passive students, and to meet the challenges of being active, ethical aspects were introduced. Especially, the Code of Ethics (CoE) for Software Engineers was especially emphasized (Gotterbarn, 1999), where students should reflect on this concept, and put those reflections in the context of the project. The CoE, as presented in the table below, constitutes a list of several aspects, such as, on software products, and development of software, and is a result of a co-operation between the ACM, and IEEE-CS.

1. PUBLIC - Software engineers shall act consistently with the public interest.
2. CLIENT AND EMPLOYER - Software engineers shall act in a manner that is in the best interests of their client and employer consistent with the public interest.
3. PRODUCT - Software engineers shall ensure that their products and related modifications meet the highest professional standards possible.
4. JUDGMENT - Software engineers shall maintain integrity and independence in their professional judgment.
5. MANAGEMENT - Software engineering managers and leaders shall subscribe to and promote an ethical approach to the management of software development and maintenance.
6. PROFESSION - Software engineers shall advance the integrity and reputation of the profession consistent with the public interest.
7. COLLEAGUES - Software engineers shall be fair to and supportive of their colleagues.
8. SELF - Software engineers shall participate in lifelong learning regarding the practice of their profession and shall promote an ethical approach to the practice of the profession.

While all of the points were under discussion, especially point 7 was emphasized. By addressing this, it was clarified that this was not only for the purposes of being fair to co-students, but actually a phase of preparing for future employability, and work, through an accepted way of looking at the profession. In (Einarson, 2013), it is shown that the introduction of the CoE at the course contributed with a correlation between how seriously students approached the CoE and the project result. Besides from those inspirational results, another implication is that further CDIO Syllabus Learning Outcomes, such as, 2.5.1 Ethics, Integrity and Social Responsibility, 2.5.2 Professional Behavior, and 2.5.6 Trust and Loyalty, are addressed to some degree, as well as 3.2.8 Negotiation, Compromise and Conflict Resolution, 4.1.1 Roles and Responsibility of Engineers, and 4.1.2 The Impact of Engineering on Society and the Environment.

What could clearly be seen was that the number of active students was increased. Still, as a common problem in project-based courses, some students were relying on the loyalty of others, where those were covering up for them. To increase the possibilities for the teacher to catch information on such occurrences, anonymous student evaluations to find the state of the course, and especially co-student contributions, was taken under consideration.

Fourth Year

During the fourth year, the course content was kept the same, but we introduced anonymous evaluations in paper format conducted during each project meeting, besides the formal digital anonymous evaluations conducted at the end of the course. The aim was to give the students the opportunity to raise their voice regarding the work and colleagues. The course instructors would keep those and go through those, both after each formal project meeting, in order to keep track of the project progress, and team evolution. The instructors would go
through those both during the course, and at the end of it. The purpose was to reveal and counteract eventual destructive loyalty where students were covering up for others (as identified during the third year). In this way, the students were given the chance to raise their voice, while still remaining anonymous, and the information revealed remaining confidential.

The format was on paper, i.e. non-digitalized format, and was based on informed consent. The evaluations were done on a voluntarily regularly basis, i.e. at every project meeting. Moreover, this also helped the students, on a meta-level, to rate their own contribution in regard to others, and at the same time relate to ethical aspects of CoE (see 7.Colleagues and 8.Self earlier discussed under Third Year section). In a way, this was calibrating their attitude towards themselves in the first place, towards the teachers, towards colleagues, and the project in itself. Furthermore, the anonymous evaluations could present foundation of eventual ongoing conflicts. This, in itself, increased the value of CDIO Syllabus Learning Outcome 2.5.2 Professional Behavior, 2.5.6 Trust and Loyalty, 3.2.8 Negotiation, Compromise and Conflict Resolution and 2.5.1 Ethics, Integrity and Social Responsibility, more specific, The moral courage to act on principle despite adversity and The possibility of conflict between professionally ethical imperatives, and Truthfulness. In addition, in order to encourage students’ active learning, the teachers decided to proceed with changing the format of the course, such that seminars were introduced during the next year.

**Fifth Year**

(Hedin 2006) distinguishes between two ways of teaching: “Sage on the Stage” and “Guide by the Side”. Whilst the former one refers to the more traditional way of teaching, i.e. through lectures where the teacher takes an active position during lectures, the latter one refers to teaching forms that are more focused on the active involvement of the student, the teacher becoming more of a facilitator. At the same time, a UNESCO report since 2009, supported the idea that “lecturing about declarative knowledge can no longer be the default method”, as shown in (Saplacan et. al. 2015). In this way, during the fourth year, the way the course was provided was shifted from traditional lectures towards a more “Guide by the Side” approach, as in (Hedin 2006). The main teaching form introduced here was a hybrid form of seminars. Initially, the seminars were structured into three parts: first, introducing a topic (that previously was a lecture); second, the students would get hands-on group assignments to work on that were relevant to the topic presented in the first part of the seminar; and finally the groups had to present their summary of discussions for each of the assignments. Here, the groups were the same as the sub-groups from the project. The intention of this way of approaching seminars was multifaceted: (1) on one hand, to create an additional discussion platform for the sub-groups which would eventually enhance the cohesion of the sub-groups; (2) to enhance the communication and cohesion between sub-groups, in order to prepare them for the later phase of the project, where all sub-groups should integrate their work, hence the cohesion of the team as a whole; (3) to discover eventual conflicts within the sub-groups that would not be acknowledged during formal project meetings; (4) to provide additional opportunities for oral presentations; and (5) to examine new perspectives on the project, but also outside of it; (6) to train skills such as time-management at a smaller scale, as the assignments given had a limited amount of time to be solved and presented. This would cover at some degree CDIO Syllabus Learning Outcomes 3.1.2 Team Operation, 3.1.3 Team Growth and Evolution, 3.1.4 Team leadership, 3.2 Communication, 3.2.6. Oral Presentation; 3.2.7 Inquiry, Listening and Dialog, 3.2.8. Negotiation, Compromise and Conflict Resolution, 3.2.10 Establishing Diverse Connections and Networking.

Although the intentions were good, the teachers (one of the co-authors of this paper) experienced that the format was a compressed one and it would be better to separate the
introductory lectures from seminars. This would give the students more room for preparations and the discussions would become deeper.

CURRENT AND FUTURE APPROACHES

During the next years, the content was kept the same. Though, the main focus here was on optimizing the process. Hence, the format of the seminars was changed from the hybrid version of one block with three parts (introductory lecture, assignment and presentation), into two main blocks. First, an introductory lecture was given, whereas the students were assigned a set of around 15-25 questions per seminar, as a preparation. Some of the questions, or variations of those, were chosen as topics for the seminar. The students had the opportunity to discuss first in group, and then present their views or reflections, as well as having the opportunity to argue for- and against for the choices made. The main observation here was that the discussions were more dynamic and interactive. In addition to the CDIO Syllabus Learning Outcomes covered during fourth year, here were observed tentative of 3.2.7 Inquiry, Listening and Dialog and 3.2.9 Advocacy as well. In addition, regarding the anonymous evaluations, experiments on two dimensional self-evaluations have been introduced. We discuss this under the next section.

EXPERIMENTS ON SELF-AWARENESS

While approaches presented above have shown how values of learning outcomes of project-based courses may increase, questions arise on how to increase those even further. To address this, experiments have been done, as outlined in (Einarson et al, 2016), where students should themselves be aware of the educational meta-process they are undergoing. Here students are exposed to iterative self-evaluations, where they respond to statements based on learning outcomes, such as those pointed out in this contribution. For that self-evaluation an online evaluation tool is used, which in turn provides a base for further discussions within the student group. While this approach still is at an experimental level, it is of significant interest to study possible impact on students’ project work, as well as on their level of self-awareness. A corresponding CDIO learning outcome of this task, may here be 2.4.5 Self-awareness, Metacognition and Knowledge Integration.

To further elaborate on this, while during previous years the main focus was on evaluating own’ and colleague’s work, this time we have introduced two dimensional (2D) self-evaluations using ZEFsurvey tool. Please see for more on (2D) self-evaluations the work in (Saplacan and Teljega 2015; Saplacan, Silvén, and Einarson 2016; Einarson, Saplacan, and Silven 2016; Einarson and Saplacan 2016). The statements (compare to questions) in the (2D) self-evaluations addressed: course learning outcomes, working life relevancy of the course/project, self-development and general questions regarding the organizations of the course. The statements were formulated by the course instructors using the pronoun “I”, e.g. “I feel I learned skills needed in working life”, “I feel I have improved my communication and cooperation skills”, “I think the experience will be beneficial for me in the job market” etc. The students had to place their answer on a 2D-scale (compare to surveys with one scale), where one axis represented the importance of the statement of them, and the other axis represented if they degree at which they agreed. In this way, by using the pronoun I and the 2D-scale, the students would become the main subject of the statements, and at least if the answers were not very exact, they would at least encourage self-awareness on how the student is positioning him/her self towards the project/course. This contributed to both
students’ and teachers’ self-awareness. We advance our discussion around this topic in the sequel.

Elements of self-awareness have been developed even on the teachers’ side. For instance, if we take the capability-maturity model (CMM), we have noticed that during the years, from a pedagogical perspective, we have taken the same steps as in CMM. Whilst in the initial phase (1), we have developed ourselves an understanding of working with CDIO-oriented projects, during the repeatable phase (2), we have introduced the CMM model. Further, during the phase (3), the defining phase of CMM, we have framed CoE for the students, but it also helped us in developing deeper understanding in the way we anchored the project – for the students. Moreover, we have introduced the anonymous evaluations, as a tool for conflict resolution and support for CoE. During the fourth phase (4), we have worked with the course from a “management” point of view, by keeping the same content, but re-structuring its format, through a hybrid version of seminars. Lastly, during the last phase, (5) Optimization, we worked with the optimization of the course, i.e. for instance, keeping the same content, but improving the format of the seminars, and by introducing 2D self-evaluations, which would contribute in their turn to both students- and teachers’ self-awareness. For instance, based on the results of the surveys, the teachers would eventually change the format or content of the course, course syllabus or learning outcomes. Other forms of changes that were applied was eventually to modify courses that were mandatory entry requirements for this course. Although our arguments here may not be described in-depth, we can see the correspondence between CMM and our pedagogical approach. At the same time, we intend to develop this approach further, in our future work, but for now we wanted to introduce it briefly in order to get a basic understanding of the concept, as an element of self-awareness on teachers’ side. We call this approach the CMM Learning Staircase. This aims also to be a potential guideline for those who would like to learn from our experience and aim to introduce CDIO-oriented projects.

However, learning is a cyclic process as show by Kolb in (Ljungblom et. al. 2012) (Jansson and Ljung 2015). So once we reach stage (5), Optimization, a new iteration through all cycles should be taken, at deeper level. For instance, by introducing different ethical frameworks that can be applied not only towards self- and colleagues, or teamwork, but also regarding the socio-technical context, see, for instance, the ethical frameworks presented in (Ess 2010).

SUMMARY

This contribution has covered several approaches to increase levels of activation of students, through several years of experiences of a project-based course in Software Engineering. Moreover, activation has been specified around a number of CDIO Syllabus learning outcomes. Those learning outcomes have been shown to reflect several levels of all four sections of CDIO Syllabus, clearly motivating that the course corresponds well to CDIO Standard 7, on Integrated Learning Experiences.

The course has, under the years, being well established, even though further experiments to further increase values of learning outcomes are implemented. While the specific project task, described in this contribution, may vary, a fundament of that establishment is still valid, and may be used generically in other project-based courses, in Software Engineering, but certainly also in courses of other disciplines.
REFERENCES


BIOGRAPHICAL INFORMATION

Daniel Einarson has a PhD in Computer Science and has several years of experience in teaching Computer Science and Software Engineering. Furthermore, he has been experimenting with several different forms for project-based learning.

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A DESIGN-IMPLEMENT CAPSTONE PROJECT IN ELECTRONICS ENGINEERING

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ABSTRACT

Starting from the first bachelor, CDIO projects are planned every bachelor year in the curriculum of our Electronic Engineering educational program. Students are expected to participate in gradually more demanding projects over the progress of their bachelor years. In this paper, the capstone project in the third bachelor is presented.

For this bachelor’s dissertation, students are required to conceive, design, implement, document and present a technically advanced project. First, a literature review is performed, followed by a functional analysis. Based on this analysis, a technical implementation is proposed, discussed and realized. The implementation is fully documented, with enough details to reproduce the work afterwards. Accurate scientific reporting and documenting are required, including proper references as well as using correct spelling, grammar and language. To present the work, a written document is produced, complemented by an oral presentation and demonstration, as well as by an academic poster. All aspects mentioned above play a role in finally grading the project work.

In this paper, the organization of the project is documented, including a project example with summarized technical information. Further sections document assessment and feedback, as well as concluding remarks to highlight the project’s benefits but also some project issues.

KEYWORDS

Design-Implement Experiences, Engineering Workspaces, Integrated Learning Experiences, Active Learning, Learning Assessment.
(Standards: 5, 6, 8, 11).

INTRODUCTION

Design-built projects are at the core of our Electronic Engineering educational program, complementary and illustrative to the more theoretic courses. These projects start from the first year of our four-year educational program. Gradually, the projects become technically more demanding, evolving from the first to the third year of the academic bachelor program, as is also the case in (Kjærgaard C et al., 2012), according to CDIO Standard 5. Additionally, reporting skills and literature analysis become more important and refined.
At the previous CDIO conference in Turku, Finland, design-built projects in the second bachelor year were presented in (Verhaevert & Van Torre, 2016). In this paper, the capstone project in the third bachelor year is presented, a project resulting into the bachelor’s dissertation. Here students are required to perform an extensive literature review and document their work using the proper references. Additionally a fully detailed functional and technical analysis should be presented in separate chapters of the bachelor’s dissertation text. The link to the (Course Specifications, 2016) is listed in the reference section.

The students work in teams of three people and select a project presented by their professors at the beginning of the second semester. The projects are linked to the research groups of our department, with specific research domains depending on the group. Coaching throughout the projects is provided by the professor as well as a number of assistants.

A full afternoon is reserved for lab work each week. Students generally see their coaches in the lab, but can also contact them outside lab hours. Feedback and communication between students and coaches are very extensive.

At the end of the project, the bachelor’s dissertation documents the results and also reflects on them. This has to be a very complete report, as outlined further in this paper. A poster is also produced by the students, presenting an overview of their work in a structured way.

A final presentation, optionally including a demonstration as a proof-of-concept, concludes the project. Grading is also commented in the last section of this paper.

Compared to all previous projects in our educational program, the bachelor’s dissertation is characterized by a larger responsibility for the student, supported by much more extensive and complete reporting, including a literature review with proper referencing. Different ways of active learning are included, as also is reported in (González et al., 2016). Considering the grading of the project, not only technical content, but also writing and presentation skills are taken into account.

**ORGANIZATION OF THE PROJECTS**

*Project Proposals*

Project proposals for the bachelor’s dissertation are produced by the different research groups supporting the Electronic Engineering educational program. The proposals are presented to the students by their professors, who also taught them previous courses. The list of projects covers the following research domains at our university:

- Wireless communication
- Image processing
- Acoustics
- Automation
- Radiofrequency circuits
- Electronics design
The students can ask further questions to the professors who presented projects which interest them to obtain more detailed information. In the next step they present a priority list of their three most preferred projects. Based on this list, students are assigned to the different projects, respecting their preferences as much as possible. Hence, the project groups of three persons per project are composed.

**Literature Review**

Once the teams are formed and have been assigned a project, the first action is to perform an extensive literature review. All three students in the team are required to perform and write separate literature reviews on different aspects of the project, of which they have to hand in a ten-page text after four weeks.

This approach guarantees a quick start, where every student comes into action. Additionally, because they perform their literature research independently and on different issues, numerous sources are discovered and are collected to be compared at a later stage.

**Technical Description and Functional Analysis**

An in-depth technical description and functional analysis should be provided by the team in the final dissertation. Students are encouraged to spend time on this part from the start, as it helps structuring their further work. Intermediate feedback from the coaches is of course also continuously available.

Students are made aware from the start that the functional analysis should be written in order to make it understandable for users of the designed system. Technical and implementation details should be presented predominantly in the technical description section.

**Hands-on Project Work**

Project work, as illustrated in Figure 1, is performed in the lab at our university on a weekly basis. According to CDIO standards, the workspaces used are student-centered, user-friendly and always accessible. One afternoon a week is reserved for the bachelor's dissertation, and at this time the coaches are always present, promoting early success, of which the importance is indicated in **CDIO standard 5**. Students are also allowed to work in the lab anytime, outside project hours. The importance of hands-on learning is stressed in **CDIO standard 6**. Weekly project meetings are organized with the coaches, resulting in a written report after each meeting, which is produced by the students.

Hands-on project work is divided between all students in the team. Depending on the specific task, a part can be performed by a single student, or by several students together. For example, drawing a printed-circuit board (PCB) is a task which is generally performed by one person. This person of course communicates with the other team members about the electrical as well as mechanical requirements.
Figure 1. Hands-on project work

Creative ideas between students and coaches are extensively exchanged, depending on the literature reviews as well as on the results from the first practical setups and tests. Often changes in planning and approach are necessary, to come to a working product.

The list of hands-on project tasks includes, but is not limited to:

- Breadboarded or soldered test setup of proposed circuitry
- Measuring the performance and properties of these circuits
- CAD of schematics and printed-circuit boards
- Etching, drilling and soldering of PCBs
- Measuring the properties of the PCB version of the circuit
- Mechanical design, including static setups as well as the use of motors and gears
- Implementation of the mechanical design
- Integration of mechanical and electronic designs
- Implementation into a working system
- Testing and measuring system components, such as antennas and their radiation pattern
- Testing and measuring the complete system

Given the variety of the tasks, the project is a valuable Integrated Learning Experience, developing multidisciplinary knowledge simultaneously with personal and interpersonal skills, corresponding to CDIO Standard 8.
**Illustration of a Project Example and a Short Technical Description**

As an illustration of the practical work, four figures are included of a project for radio direction finding. Here, a system is designed and implemented in order to automatically rotate a pair of antennas towards a signal source. The direction of the source is assessed, depending on the phase offset between received signals. All tasks included in the preceding list are required for this project.

In short, the project involves a pair of antennas, switched alternating to an FM receiver. If the signal source is not modulated, the sound intensity produced on the FM receiver is proportional to the phase difference between the signals impinging on the two antennas. As the phase difference is proportional to the difference in physical distance travelled by the radio waves, it is possible to orient the antennas in order to find the minimum sound intensity. When this point is reached, both antennas are at the same distance to the source and hence the direction of the source is known, however, with a 180 degree ambiguity in azimuth, an ambiguity which is resolved and explained further.

Figure 2 shows a PCB implementing the electronic antenna switching network. No moving parts are involved into the switching. Figure 3 displays the base of the system, including the electronics and mechanical setup using a stepper motor to rotate the antennas by means of a microcontroller. The device in front of the image is the FM receiver, of which the audio output is sampled by the microcontroller and the input is connected to the antenna switching network. Figure 4 shows the complete system for test and measurement into an anechoic chamber. Figure 5, finally, displays a measurement illustrating the phase difference between the switching control waveform and the output of the FM receiver. Based on this phase difference, the 180 degree azimuth ambiguity is resolved in the embedded software. Signals are in phase or have opposite phases, depending on whether the signal source is in front of, or at the back of the antenna pair.
Figure 3. Electronics and mechanical construction

Figure 4. Measurement of the complete system
Figure 5. Measurement results illustrating the importance of phase relationships, and resolving the 180 degree azimuth ambiguity (see text)

DOCUMENTING THE PROJECT

Literature Review

In the first weeks of the project an extensive literature review is performed by each team member. The information collected at this stage is reviewed and summarized into the final bachelor’s dissertation, which is presented as one document and thus one literature review per team.

Poster

An academic poster is required and should be included as a folded A5 formatted page in the bachelor’s dissertation, which is an A4-format document. Guidelines are available for a good poster design and feedback from the coaches is also available during the semester.

Bachelor’s Dissertation

At the end of the semester, the bachelor’s dissertation is handed in, structured into the following sections:

- Literature review (summary of the three separate reviews)
- Problem description
- Functional analysis
- Technical analysis
- Measurements and results, including figures and tables
- Conclusions
- References

All these parts have to be included and are separately assessed in order to calculate the overall grade for the project.
PROJECT ASSESSMENT AND FEEDBACK

Weekly Project Meetings

Weekly project meetings during the semester allow continuous feedback, without presenting marks or grades. In these project meetings the coaches also monitor how the project advances compared to its planning, which is represented on a Gantt chart. Project planning is generally dynamic during the course of the project, and the students are guided by their coaches in regularly updating their planning according the current status of the project, in order to set intermediate deadlines and reach their targets.

Presentation

Only one presentation is performed for the whole team, but every team member should have an equal oral contribution. The presentation is assessed by the coaches as well as by a language professor, specialized in presentation skills and correct writing and reporting.

Therefore the feedback does not only concern the contents of the work, but also the presentation of the work itself.

Demonstration

An optional demonstration can be performed, for those projects to which this is applicable. Projects leading to a successful hardware or software development are ideal for these demonstrations.

If hardware setup should be too elaborate or complicated on the presentation day, a movie can be an interesting and accepted alternative. Students are encouraged to document results in pictures and movies whenever possible, which should also be available as a backup when a planned live demonstration fails.

Assessment

Assessment is arguably the most important part of the project. Of course, the main goal of the project is to allow the students to learn as much as possible.

However, according to CDIO Standard 11, it is highly important to have an effective assessment process for measuring the different learning outcomes. Therefore a strict system is used, which is known to the students from the beginning of the semester. The final marks are composed as follows:

1st exam chance:

- 20 % Individual assessment on personal literature review and report
- 20 % Permanent assessment during contact hours
- 10 % Group score on poster
- 30 % Group score on final report
- 20 % Presentation and demonstration

2nd exam chance (in case of failure in the 1st exam chance):
• 50 % Report on additional individual assignment
• 50 % Oral presentation and demonstration of additional individual assignment

Feedback

Feedback to the students is provided in a variety of ways.

During the semester all students are trained in small groups (different from the bachelor’s dissertation groups) in their presentation and writing skills by the language professor. Considering writing and presentation skills, immediate oral feedback is presented to the team at the end of their bachelor’s dissertation presentation, by the coach who is specialized in these topics.

Additionally, the professors and assistants who operated as coaches during the semester provide feedback about technical contents of the presentation and ask technical questions to further assess the student’s insight into the project work.

After reading the text and assigning the overall marks, further detailed feedback is available to the students on demand. This extra feedback is only requested by students who do not agree with their marks, which is generally not the case because of the transparency of the system.
COMMENTS

The bachelor's dissertation project is a multidisciplinary educational experience, further stimulating teamwork and developing project planning and management skills. Engineering skills are also refined, according to CDIO principles. Additional to previous projects in the Electronic Engineering curriculum, research skills are required to perform a literature review and to write and present a scientific document, including the proper references in IEEE format. Written and oral communication are explicitly assessed and taken into account for grading the project. The project allows the students for the first time to perform a full scientific project development cycle, which is a clear strength of this course.

Some weaknesses also exist, but are hard to exclude, given the nature of the project. For example learning is very concentric, focusing predominantly on those topics that are necessary for the project. Students tend to choose a role in the project, corresponding to their own strengths, which are then further developed, while their weaknesses stay uncompensated. However, as the students advance further in their curriculum they generally develop their own priorities and later choose jobs where they can employ their specific strengths. In this context it is probably not required to aim for more diversity in their work for subsequent projects. Note that, although each student has specific tasks, each student is also required to have a good overview of the complete project.

At the moment, projects are mostly linked to research work performed by the professors. An opportunity exists to perform project work that is more closely related to specific industrial demands. Providing an industrial link could go as far as having students perform part of the project work in a company. In such an environment, students could acquire experience which is complementary to the knowledge which exists in the academic world. Another issue is that the pool of projects linked to the professors' research is limited. Therefore it is difficult to propose entirely different projects each academic year. An industrial link could provide new ideas and relevant project topics, as described in (Lundheim et al., 2016).

CONCLUSIONS

This article described the bachelor's dissertation CDIO project, performed as a capstone project for the 3rd bachelor year. For the first time in the curriculum, the project offers the students a full development cycle. This cycle starts with an extensive literature review, with proper referencing, and includes project planning and management, engineering and scientific reporting in a written as well as oral form.

The project is very successful and motivating for the students. In a regular curriculum, the third bachelor year is followed by a master year, including a master's dissertation. Therefore the CDIO course discussed in this paper is not only serving as a bachelor program's capstone project, but is also an excellent preparation to the master's dissertation and its corresponding more extensive research project.
REFERENCES


BIOGRAPHICAL INFORMATION

Patrick Van Torre, Ph.D. received the Electrical Engineering degree in 1995 and the doctoral degree at Ghent University, Belgium in 2012. He has been employed by Ghent University, at the Faculty of Engineering and Architecture since 1999, where he teaches theory courses in Electronics and ICT, organizes project-oriented lab sessions and is involved in hardware development projects for third parties. He is active as a researcher, in the field of wireless communication, focusing on body-centric multiple-input multiple-output (MIMO) and beam-forming systems.

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POGIL BASED CLASSES FOR COMMUNICATION ENGINEERING COURSE

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ABSTRACT

This paper summarises the research carried out on the active learning technique “Process Oriented Guided Inquiry Learning” (POGIL) in communication engineering course. The contents of Communication Engineering (CE) are highly theoretical and involves more of analytical work. Traditionally this course was taught by mere lecturing in passive learning style. This passive learning made the generation Y learners to do rote learning for the assessment purpose. These series of activities lead to unemployability irrespective of their grades. To achieve the desired learning outcomes, educationalist worldwide follows different active learning techniques including inquiry based learning. Inquiry-based learning incorporates directed questions which enhances the student’s critical thinking skills and makes the students to construct the knowledge on their own. Concurrently it needs the following i) specifically designed instructional activity sheets from the instructors for learning ii) Accurate assessment of prior knowledge for overall improvement in learning and iii) scaffolding interventions by the instructor to pay for the increased cognitive demands on beginners. This paper discusses how POGIL can be applied in CE course and how CDIO syllabus can be framed by designing a project based on POGIL approach. It also discusses how CDIO framework can be adopted within the already available curriculum framework with minimal change.

KEYWORDS

CDIO, POGIL, pedagogy, Construction of Knowledge, Standards 2, 3 & 5

INTRODUCTION

Conceive, Design, Implement and Operate (CDIO) (Crawley., 2012) and Outcome Based Education (OBE) (2013) are two different standards set by education sector worldwide to access the standard of higher education Institution. Both standards talk about innovative pedagogy to promote active learning and to improve the critical thinking skills of the students. Though there are wide number of innovative pedagogy papers in fields like medical science and chemistry, very less number of documented papers exist in engineering education. In
India professors got the awareness only when OBE started with an objective of students centred learning. Since the establishment of the student centred learning many active learning techniques like Think Pair Share (TPS), Peer Instruction (PI) learning and Z-A learning are followed worldwide. The objective of these active learning techniques is to make the students active in the class room and to promote complex thinking skills. In addition, to active learning, CDIO talks about Engineering as a practice, which cannot be obtained by a mere active learning. In other words, the idea of the CDIO initiative is located at the intersection between the notion of active learning and the essential sciences of applied engineering.

Problem based learning (P1BL) (Barrows., 1980 & White., 2007), Project Based Learning (P2BL) (WeiZhan et al. 2011), inquiry based learning and Process Oriented Guided Inquiry Learning (POGIL) are some of the other active learning pedagogy widely followed. These pedagogies not only promote critical thinking skills, but also act as a guide to solve a real problem existing in practice. CDIO and P1BL are not mutually exclusive and they are compatible and reinforcing (Edstrom et al. 2012). By defining innovative pedagogy as a tool to provide the three categories of innovation competencies: individual, interpersonal and networking innovation competences Taru & Juha Kontio (2014) have related the innovation pedagogy to CDIO. Though it is true with P1BL and P2BL without curriculum change it would be too difficult to bring in networking innovation competence at least with respect to course syllabus completion, i.e. if it is followed for introductory courses like Circuit Theory (CT) one would end up completing only 60% course coverage. In most cases, coherent and ambitious programmes of reform involve project-based education within authentic professional engineering contexts.

This paper has been divided into four parts, where the first part reviews relevant background on active learning and POGIL, compares CDIO to active learning. Second part explains the development of activity sheet with an example for conceptual level understanding topic. The third part analyses the feedback received by the students and the last part relates the work to CDIO standard and finally the paper has been concluded with future direction

POGIL ACTIVITY SHEET DEVELOPMENT

The students who have practiced only for what, explain, derive, and solve (all related to what they studied obviously in the class room already) when confronted with even why (why such methodology is not suitable for some X application?) find it very difficult. In such condition the main goal is to guide learners so that they learn to utilize the information in ways that are consistent with the learning objectives, to store the information in long-term memory (Kirschner et al, 2006, Elliot et al, 2014 & Lawson 1995). POGIL appears to accomplish this goal, while still engaging the students and restricting the traditional, lecture format. The necessary information is provided to students in POGIL and hence does not overload the cognitive processing of working memory, as found in the PBxL method. POGIL, is found to be effective in engaging students because of its carefully structured activities, which focus on the processes of learning (David., 2003).

The following strategy is defined for the creation of learning material. The first step is to systematically analyse the contents to come up with minimum common learning content or a structure to be followed throughout. Next step is to identify if there is any prior learning required? If so, teach the students the minimum required prior knowledge content along with the required common content and complete it in few classes. Third step is to prepare the
activity sheets with critical thinking questions based on their prior knowledge and the minimum common content already taught. With respect to this, two kinds of activity sheets were created based on the content difficulty level. For conceptual understanding, lasting effect on student was made by creating the contents linking with day to day activities. For higher cognitive level, questions were prepared by going deep into the content for activity sheet creation. By solving the activity sheets in group together with the guidance by the instructor, students were supported to master the basic knowledge of communication engineering. Also, it challenges the students to adopt to any new problems.

The POGIL activity sheet has been developed with most care and it followed four level approach (Abraham., 2005) i.e. orientation, exploration, concept formation and application. The orientation stage prepares the students for learning by introducing the learning objective. In the second stage students use the models or activities created by the instructor for analysis and investigation of the data. In the third stage, they invent the concepts. This process is enabled by supplying questions that compel students to think critically and analytically as they engage in the exploration. These questions, which are called guided-inquiry, critical-thinking, or key questions, guide the learner both in the exploration and concept invention stages. The steps are illustrated with two examples.

**POGIL Activity sheet for concept of Modulation**

Generally, the concept of modulation will be given as a lecture or like a definition in the traditional teaching format. In contrast, in POGIL a model or relevant data must be provided with structured directed questions. As the concept of modulation is very abstract, a different context rich domain representation was used to visualize and understand the technical concept. The MATLAB simulation can be used in this place, but to make the weaker students also to have the concept in their long-term memory an equivalent day to day model is needed. This facilitates easy comprehension and overcomes language barriers of rural and weaker students, who respond better to some visualization. Hence students were given images and asked to make inferences with the help of the POGIL questions. The visualizations are shown in figure 1a through 1f.

![Single tone sine waveform](image1a.png)  ![Collection of small bottles](image1b.png)
Table 1. Inquiry questions for explaining modulation

<table>
<thead>
<tr>
<th>Fig No with Question</th>
<th>Inquiry Questions</th>
<th>Expected Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a.</td>
<td>What is the frequency of the waveform shown in figure. Answer can be relative low or high with respect to figure 1c.</td>
<td>Low</td>
</tr>
<tr>
<td>1b-1</td>
<td>What is shown in Figure</td>
<td>Small Bottles</td>
</tr>
<tr>
<td>1b-2</td>
<td>Can you carry those bottles as it is to short or long distance? Why?</td>
<td>May be for short distance fine, But for long distance we cannot, because they are small individual pieces difficult to carry in hand</td>
</tr>
<tr>
<td>1a-2</td>
<td>Realate the collection of small bottles concept with low frequency information for transmission to long distance</td>
<td>As like small bottles, low frequency can be transmitted only for short distance not for long distance</td>
</tr>
<tr>
<td>1c-1</td>
<td>Compared to Figure 1a what is the frequency of this waveform?</td>
<td>High frequency</td>
</tr>
<tr>
<td>1d-1</td>
<td>What is the figure shown in figure? And its size compared to 1b ?</td>
<td>It is bag, bigger than those bottles. Sometimes we call it as carry bag.</td>
</tr>
</tbody>
</table>
**STUDENTS FEEDBACK AND FINDINGS**

POGIL classes were conducted for II-year ECE Vel Tech University students for CE course. The students are from heterogeneous group whose marks range from as low as 50% to as high as 95%. Therefore, the absorbing capability of students is varied. Accordingly, 20% of the students are grouped as more than average 50% students are grouped as average and 30% students are grouped into below average. However, students were not informed about their categorization. A set of questionaries were framed in order to have the formal feedback from the students about the PGOIL classes. There were two types of questions framed objective type and descriptive type. Objective questions were framed in order to guide the students to answer descriptive questions. The questions were given in table 2 & 3. It was not a surprise to see only 70% of the students have answered for the descriptive type due to lack of real interest and the objective questions were answered randomly. The feedback data analysis showed that the above 60% feedback is either from above average or average students. The feedback data was analysed with reference to three points i)group work ii)knowledge construction iii) Final assessment.

<table>
<thead>
<tr>
<th>S.No</th>
<th>Feedback Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>What do you think about the questions for self-understanding in POGIL classes</td>
</tr>
<tr>
<td>2</td>
<td>Do you like to have more questions? If yes or no why?</td>
</tr>
<tr>
<td>3</td>
<td>Do you like to have POGIL classes in future? If no state the reason</td>
</tr>
<tr>
<td>4</td>
<td>What is the difficulty in recollecting old topics or old concepts studied in the previous semesters?</td>
</tr>
<tr>
<td>5</td>
<td>Does POGIL classes reduce your time to review the same topic for exam?</td>
</tr>
<tr>
<td>6</td>
<td>What did you like most about the POGIL Classes?</td>
</tr>
<tr>
<td>7</td>
<td>What do you think that should be improved in POGIL classes</td>
</tr>
<tr>
<td>8</td>
<td>Do you like to work in group ? If no what is the difficulty</td>
</tr>
</tbody>
</table>

Table 2. Descriptive Feedback Questions
Table 3. Objective Feedback Questions and Survey results

<table>
<thead>
<tr>
<th>S.No</th>
<th>Objective Feedback Questions</th>
<th>Agree %</th>
<th>Undecided/not answered %</th>
<th>Disagree %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>POGIL activity has helped me learn concepts more effectively than lecture alone would have</td>
<td>70</td>
<td>25</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>The POGIL approach has forced me to think more deeply about concepts than the lecture alone would have</td>
<td>65</td>
<td>25</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>The POGIL approach has helped me feel more confident about tackling unfamiliar problems</td>
<td>50</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>The POGIL classes has been effective in improving my problem-solving skills</td>
<td>40</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>The POGIL classes has helped me improve my communication skills</td>
<td>60</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>I think the POGIL classes has helped me improve my teamwork skills</td>
<td>60</td>
<td>40</td>
<td>0</td>
</tr>
</tbody>
</table>

**Group Work**

With respect to group work students were more interested in learning in group, but it is mostly because there is no higher authority there to direct them or they are comfortable in their mother tongue as the instructor language and the students language were different. The main motivation for group learning is the language fear initially and slowly they learnt to like at the end. Group learning is a good sign but it was not reflected in the assessment results. However the above average students were keen in giving their answers before anyone else rather than engage in discussion with their group members. It shows that students have to be practiced for group work from the beginning.

**Assessment**

The university conducts four internal assessment tests and one end semester exam. The evaluation questions were prepared by the course handling teachers for the internal assessment tests, whereas it was prepared by the externals from other university with the help of the outcomes given in the syllabus. The internal assessment results were always good with the students who followed POGIL classes compared to the students without POGIL. The end semester exams also had a similar statistics. However it is quite different i.e. the expected result was more due to the practices they already had during their all four internal tests. The declining result was because in most of the cases the evaluation questions were not based on the outcome i.e. in some cases it was understood in a different context. For example in CE course the modulation can be dealt only with respect to mathematical equations which describes the modulation in black box level or the electronics involved in modulation. The exact assessment is possible only when the course syllabus,
course outcome and evaluation questions prepared by the course instructor who follows the innovative teaching learning. Hence it is very difficult to practice any kind of innovative learning in a system heavily oriented towards textbooks driven examinations.

**Knowledge Construction**

Most of the objective as well as descriptive questions were based on the knowledge construction. The statistics from the above table shows that, though it was easy for most of the students to understand the concept, applying the same to higher level was very difficult. Even within the above average class of students, they expect the instructor to feed the knowledge to them. This is only because of the attitude of the students to change from the exam pattern they were trained so far. Hence it is highly essential that, the members of the education system i.e. from the management, higher level authorities, instructor to students in inquiry-based courses must show some characteristics for the success of any innovative teaching practices including POGIL classes.

The collective students feedback can be grouped into three different categories i.e. Assessment, Group work and Knowledge construction. Always the higher learners made sure their presence by answering before their discussion with their peers. In a country like India, where the competition culture is deep rooted the idea of team work has to be improved a little bit. Knowledge construction has definitely happened and is reflected in their grades in internal assessment. Students usually confuse between the frequency of the carrier and the information signal. Here they had very good long lasting effect that at any time they compared the carry bag with the carrier used in modulation. The end semester exams also had a similar statistics. However it is quite different i.e. the expected result was more due to the practices they already had during their all four internal tests. The declining result was because in most of the cases the evaluation questions were not based on the outcome i.e. in some cases it was understood in a different context. For example In CE course the modulation can be dealt only with respect to mathematical equations which describes the modulation in black box level or the electronics involved in modulation. The exact assessment is possible only when the course syllabus, course outcome and evaluation questions prepared by the course instructor who follows the innovative teaching learning. Hence it is very difficult to practice any kind of innovative learning in an independent assessment system.

**CDIO CONNECTION**

In the context of this paper it is customary to describe the connection between the innovative pedagogy followed i.e. POGIL and CDIO standard. It is very simple to establish the connection with OBE as the pedagogy is the medium to achieve only the course learning outcomes. However, CDIO needs a practice based learning, which means a realistic scenario at the work place needs to be emulated. Practice does not mean P2PBL as does not involve the students in the process followed in Industries. Experiential learning can always be used to achieve this and its connectivity is established by Claire (2014) for polytechnic education. In the current Indian scenario in private universities and colleges it is very tough to follow experiential learning due to two factors i) System has not yet been matured in terms of assessment and evaluation ii) Non-availability of experienced faculty. As a complete CDIO syllabus cannot be designed in short time, it is the self-interest of the author to frame a CDIO project with the motivation from higher management, for interested students to test on pilot basis. By designing the project a part of the CDIO syllabus (standard 3) has been arrived and this CDIO project has been discussed with respect to conceive design and implement (CDI) phase.
Conceive

The conceive phase from the Instructor perspective is to design the curriculum for engineering education by engineering practice context. With respect to this, with the existing curriculum and syllabus, the number of design experiences in the complete ECE curriculum can be divided into 4 each one in the following field:

- Communication Engineering
- Embedded systems
- Signal Processing
- VLSI design

The students who would like to get into research can opt for theory based courses with at least two projects during the entire program. In communication engineering field, the design project considered is “Design and implementation of community based low power FM radio Transmitter and Receiver” for Veltech University. This project can be taken by any students after completing Analog Electronics (AE), Circuit Theory (CT), CE and Antenna course. In an era of software defined radio, doing the hardware based FM Transmitter/Receiver will seems to be trivial. But in the author, point of view, if the students are strong in basics they can apply to any advanced technology that will come in future. Also, as CE course falls in the early semester not all the students will be comfortable with using the software application package or using the microprocessor for designing the radio receiver. The aim of the project is to promote the ability of the students to describe, anticipate and plan for some of the realistic factors that are encountered in an engineering project. In students point of view the project requirement or the context is to come up with the good broadcasting system for any immediate university message when there are no other advanced technologies are existing like network down time. The goals or Learning outcomes of the CDI project are derived according to the specific objectives (standard 2) of the CDIO syllabus given by Edward (2001) and is given in Table 4.

Table 4. FM Transmitter Design Learning Outcomes:

<table>
<thead>
<tr>
<th>S.No</th>
<th>Learning Outcomes</th>
<th>Skills Acquired and CDIO syllabus outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Recognize the application of the disciplinary knowledge in action</td>
<td>Technical (2.1)</td>
</tr>
<tr>
<td>2</td>
<td>Design and develop the electronics circuit and understand how the different parts of this electronics circuit function together to make an FM transmitter</td>
<td>Technical (4.2, 4.3 and 4.4)</td>
</tr>
<tr>
<td>3</td>
<td>Explain ways in which critical thinking, creativity, problem-solving and experimentation are required in designing and implementing the proposed FM Transmitter/Receiver Project</td>
<td>Technical (2.1, 2.2, 2.3 and 2.4)</td>
</tr>
<tr>
<td>4</td>
<td>Describe the need for modules based design and hence the importance of team work</td>
<td>Interpersonal (3.1 and 3.2)</td>
</tr>
<tr>
<td>5</td>
<td>Explain the challenges faced during the design and implementation</td>
<td>Technical (2.4, 4.4 and 4.5)</td>
</tr>
<tr>
<td>6</td>
<td>Anticipate and plan for factors that are encountered in an engineering project</td>
<td>Team Work and Technical (3.1.3.2, 4.3 and 4.4)</td>
</tr>
</tbody>
</table>
Describe need for good documentation of designs and implementation processes

Personal (3.2 and 3.3)

Explain the FCC regulations for getting licensed spectrum

Interpersonal (3.2 and 3.3)

Realise importance of designing with quality and inherent safety with the public in mind

Interpersonal (4.1)

**Design and Implement Experience (standard 5)**

The team must work with realistic factors like customer requirements, government regulations on spectrum allocations and power transmission. Investigations on the customer requirement should be made by the team to arrive at the design and engineering considerations. FM transmitter Receiver is a very basic project with multiples of design availability and hence the students are encouraged to learn the design through multiple trial process. In each of the phases a set of inquiry questions in three phases as in POGIL were developed to guide the students. Conceive phase questions will make the students to critically analyse the customer requirement to go for design in abstract level. Design phase questions will make them to analyse the current design and go for a specific design in implementation phase.

**Framing CDIO syllabus**

The syllabus has been framed for the objectives listed in Table 1. As students fail to apply the concepts they already learnt and performed well in another context, it has been decided to include part of the contents from AE, CE, and CT i.e. whichever is directly applicable in designing FM transmitter. As the Antenna course is already in 5th semester it is not repeated in the syllabus specific to CDIO. While it is necessary to give design and practice experience as per CDIO standard it is also essential to provide research based knowledge which will come only through much of theoretical understanding. Hence the outcome of the basic core courses like CE are not very much towards practice and is given below in Table 5 unit wise

| 1.1 | Compare the performance characteristics of different amplitude modulation techniques |
| 1.2 | Derive the AM expression for the given AM transmitter and receiver system block diagram |
| 1.3 | Explain how AM superhetrodyne receiver performance is better than Tuned Radio Frequency receiver |
| 2.1 | Compare the performance characteristics of different angle modulation techniques |
| 2.2 | Derive the AM expression for the given AM transmitter and receiver system block diagram |
| 2.3 | Explain how FM superhetrodyne receiver performance different from AM receiver |
| 3.1 | Discuss different types of noise present in the communication receivers |
| 4.1 | Compare the noise figures in different modulation system |
| 5.1 | Solve problems on source coding |
CONCLUSION

In the first part of this paper a systematic way of developing POGIL worksheet has been addressed and its impact on students grade also has been analysed. It is found that the average and below average students were not happy with the new pedagogy followed because despite their hard work the independent examination system did not give them expected grades. In the second part a CDI project has been designed to attain specific CDI goals. CDIO syllabus has been framed through the CDI project. A similar approach can be followed to design other CDIO projects in the remaining fields like embedded system in the higher semester. Framing the syllabus is not the end; an excellent assessment process also needs to be evolved. If the assessment system for the project is also an independent evaluation system, then total CDIO process will be a catastrophic failure.

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THE EFFECT OF USING “LEARNING-BY-DOING” APPROACH ON STUDENTS’ MOTIVATION IN LEARNING DIGITAL ELECTRONICS

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School of Engineering, Nanyang Polytechnic, Singapore

ABSTRACT

First-year students from the Diploma in Telematics and Media Technology (DTMT) course in the School of Engineering at Nanyang Polytechnic, Singapore learn Digital Electronics through the “learning-by-doing” approach during their first semester at the polytechnic. They learn digital electronic circuits by designing and implementing a prototype of a practical digital security system. The students are also required to come up with innovative ideas of applying the digital security system in everyday life and showcase these ideas in an exhibition, which serves as an additional platform for students to develop their interpersonal skills. Students from the DTMT were found to be more motivated and interested in learning Digital Electronics, as compared to students from another diploma course where they learned Digital Electronics in the traditional way of attending lectures, tutorial classes and practical laboratory sessions. This paper shares our experiences in adopting the “learning-by-doing” approach in the teaching of Digital Electronics where instruction is designed to engage students in direct experiences that are tied to real world situations, and to develop students’ interpersonal skills. Key findings from the data collected through surveys and interviews are summarized in this paper to highlight the effect of the “learning-by-doing” approach on students’ motivation in learning.

KEYWORDS
Learning by Doing, Module Effectiveness, Motivation in Learning, 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 Telematics and Media Technology is a course; Digital Electronics is a module.

INTRODUCTION

Students from the Diploma in Telematics and Media Technology (DTMT) course in the School of Engineering (SEG) at Nanyang Polytechnic, Singapore learn the concepts and skills of Digital Electronics (DE) through the “learning-by-doing” approach which allows students to build their understanding of concepts through a process of inquiry and reflection.
The key objective of adopting this “learning-by-doing” approach in teaching first-year DTMT students on DE is to motivate them and increase their interest in the module. The “learning-by-doing” approach adopted in DTMT follows the experiential learning model promoted by the Experiential Learning Project Group (ELPG) from University of California Science, Technology and Environmental Literacy Workgroup. Experiential learning has been described as a pedagogy that motivates students (“Experiential learning defined”, 2016), as it encompasses various motivational strategies identified by researchers (Ambrose et al., 2010).

There are several models that characterize the cyclical learning process of experiential learning, ranging from a one-step model to a six-step model (Neill, 2002). We adopted the three-step model by ELPG in our module design, which identifies the steps as “experience”, “reflection”, and “application” (“Why EL?”, 2016). This three-step model is adapted from Kolb’s four-step model (1984) of “concrete experience”, “reflective observation”, “abstract conceptualization” and “active experimentation”. In the three-step model, a lecturer acts as a facilitator to provide challenges, encourage risk taking, correct errors, and provide context. Students, on the other hand, build experiences when they are involved in doing a task (the experience phase), share their observations and process the experiences by discussing and analyzing (the reflection phase), and deepen their understanding of the concept through applications (the application phase). In this cyclical learning process, students have the opportunity to try independently on their own and possibly fail. It is through this experience of failing that provides the most important learning opportunity for students, and it acts as stepping stones towards students’ success in real life.

Module Design

Based on the three-step model, the module design is summarized in Table 1. The first part of the instruction is designed to introduce to students the concepts of DE, teamwork, thinking and problem-solving skills. In the second part of the instruction, students work individually on his/her first project in building and developing a practical system that demonstrates the principles of DE circuits, and get themselves familiarised with the necessary tooling and experimentation skills.

In the final part of the instruction, students are assigned into groups to work on their second project where they are given the freedom to come up with different ideas of application prototypes for the DE circuit system they have developed in the second part of the instruction. The students are expected to apply the DE skills learnt in developing a real-life project prototype. The whole learning process aims to excite and motivate them to deepen their learning of DE concepts.
Table 1. Module Design

<table>
<thead>
<tr>
<th>60 Hours of Instruction – 4 hours per week over 15 weeks</th>
</tr>
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<tbody>
<tr>
<td>Week 1 to 2</td>
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<td>Week 3 to 9</td>
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<td>Week 10 to 14</td>
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<tr>
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<tr>
<td>Week 15</td>
</tr>
</tbody>
</table>

This implementation contrasts the traditional way of learning DE in other courses, where theories and concepts of DE are learned through lecture and tutorial classes, and verified through practical laboratory sessions.

**Individual Project – Security Entry System**

The project is designed for the students to get familiar with DE components (such as basic logic gates, encoder, latch, comparator, etc.), DE circuit diagrams and concepts (such as Boolean Algebra, Karnaugh Map and combinational logic design), and prototyping tools. Students also learn experimentation skills through the process of building a security entry system (Figure 1). They are guided to prepare component layout diagram, solder and/or wire-wrap the components onto the prototyping board. Every student is required to understand each part of the circuits before they start to work on the circuit connections on the prototyping board. They are also expected to perform functional tests for their circuit board.

The project provides a platform for the students to understand the practical applications of their basic knowledge learnt about DE through first-hand experience. The students would most likely face some challenges in troubleshooting their mistakes made along the way. They would then be guided to solve the problems through their reflections upon self-discoveries and/or discussions with the lecturer or their peers. They also learn how to persevere through failures. After the completion of the individual project, every student is expected to share their learning experiences with the class. This process facilitates peer-
learning in the class. Through this project, the students are able to build up their technical capabilities and gain confidence for the group project.

Figure 1. Security Entry System (Individual Project)

**Group Project – Prototype Design**

For the group project on prototype design, students are grouped into teams of two or three members each. The teams are given the freedom to come up with different ideas for the innovative prototype (examples are shown in Figure 2) they are tasked to design. All the prototypes are to incorporate the security entry system that the students have built. As it is a group project, members within a team are assigned different responsibilities, such as designing and building the prototype, sourcing materials for the prototype, and presenting their project. Though the students are expected to integrate the security entry system into their prototype designs, they are allowed to make changes to the connections if necessary, in order to fit the circuits properly into their prototypes. In this process of trying and fitting the wire connections into their prototypes, they are expected to learn through multiple failures. With the guidance and support provided by the lecturer, it is hoped that the experience of these failures motivates the students to learn and do more in order to complete a successful prototype.

Figure 2. Prototype Designs (Group Project)
In order to motivate and excite the students further, a voting competition is held at the end of the semester. The students are to invite their friends, lecturers and parents to visit the exhibition that showcases their prototypes. During the exhibition, the students pitch their ideas to win votes from the visitors. This whole learning experience intends to enhance students’ teamwork, communication and presentation skills, and also allows them to practise problem-solving skills.

INITIAL FEEDBACK FROM STUDENTS AND FACULTY

At the end of the first semester of every academic year, a survey is conducted to gather feedback from the DTMT students on the module. The students are asked a series of questions that seek to validate the objectives and the delivery of the module.

Table 2. Results from Previous Surveys Conducted in 2013 and 2014

<table>
<thead>
<tr>
<th>Do you agree?</th>
<th>Students’ Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The learning objectives of this module are clear.</td>
<td>100% agreed 100% agreed</td>
</tr>
<tr>
<td>2. The module is well organized.</td>
<td>100% agreed 100% agreed</td>
</tr>
<tr>
<td>3. The pace is just right.</td>
<td>100% agreed 94% agreed</td>
</tr>
<tr>
<td>4. The module stimulates my interest to learn more about DE and my engineering discipline.</td>
<td>100% agreed 100% agreed</td>
</tr>
<tr>
<td>5. The module is relevant to other modules in the same semester.</td>
<td>100% agreed 94% agreed</td>
</tr>
<tr>
<td>6. Feedback provided by lecturers is helpful and timely.</td>
<td>100% agreed 100% agreed</td>
</tr>
<tr>
<td>7. Grading criteria are clear and fair.</td>
<td>100% agreed 89% agreed</td>
</tr>
<tr>
<td>8. Overall, the module is worthwhile.</td>
<td>100% agreed 100% agreed</td>
</tr>
</tbody>
</table>

The results from the surveys (Table 2) conducted in 2013 and 2014 indicated that majority of the students agreed that the learning objectives were clear and found the module to be well organized and conducted with the right pace. They appreciated the relevance of this module to other modules they studied. Grading criteria of the module were also deemed clear and fair. These results reflected the success of the module delivery in incorporating strategies that help to increase the value students placed on the learning activities created for them, as well as strategies that strengthen students’ expectancies. These strategies help to create an environment that supports motivation in learning (Ambrose et al., 2010).

Most students commented that they enjoyed the “learning-by-doing” approach. They also found the module helpful in developing their interest, and they wanted to learn more about DE and their engineering discipline. The students reflected that they liked the hands-on experience of developing projects in teams, which allowed them to learn more effectively through self-discoveries and to persevere through their failures.

More significantly, the lecturer also observed that these DTMT students were much more engaged and motivated to learn more about DE during the lessons, as compared to students studying similar module in other courses. The DTMT students were enthusiastic in
completing their projects and were excited in participating in the project exhibition and competition.

INVESTIGATION ON STUDENT MOTIVATION

With the positive feedback received from students and lecturer, we wanted to conduct further study to measure the effects of the “learning-by-doing” approach on students’ motivation in learning DE as compared to the traditional approach of conducting lectures, tutorials and labs. In this study, we used a mixed method to collect data for analysis. The Intrinsic Motivation Inventory (IMI) (2016) was used to collect quantitative data, and interview with selected students was conducted to collect qualitative data.

The IMI was developed by Ryan (1982) and his colleagues from the Rochester Motivation Research Group. It has been widely used in studies related to intrinsic motivation and self-regulation (Wang et al., 2011; Loukomies et al., 2013). The IMI comprises of seven subscales with 45 items. The seven subscales are interest/enjoyment, perceived competence, effort/importance, value/usefulness, pressure/tension, perceived choice, and relatedness. For every item, the students taking part in the survey have to indicate how true the statement is describing their experience while performing a given activity on a Likert scale from 1 (not true at all) to 7 (very true).

Table 3. Selected Subscales of IMI

<table>
<thead>
<tr>
<th>1) Interest/Enjoyment</th>
<th>2) Perceived Competence</th>
<th>3) Effort/Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>• I enjoyed doing this activity very much.</td>
<td>• I think I am pretty good at this activity.</td>
<td>• I put a lot of effort into this.</td>
</tr>
<tr>
<td>• This activity was fun to do.</td>
<td>• I think I did pretty well at this activity, compared to other students.</td>
<td>• I didn’t try very hard to do well at this activity. (R)</td>
</tr>
<tr>
<td>• I thought this was a boring activity. (R)</td>
<td>• After working at this activity for a while, I felt pretty competent.</td>
<td>• I tried very hard on this activity.</td>
</tr>
<tr>
<td>• This activity did not hold my attention at all. (R)</td>
<td>• I am satisfied with my performance at this task.</td>
<td>• It was important to me to do well at this task.</td>
</tr>
<tr>
<td>• I would describe this activity as very interesting.</td>
<td>• I was pretty skilled at this activity.</td>
<td>• I didn’t put much energy into this. (R)</td>
</tr>
<tr>
<td>• I thought this activity was quite enjoyable.</td>
<td>• This was an activity that I couldn’t do very well. (R)</td>
<td></td>
</tr>
<tr>
<td>• While I was doing this activity, I was thinking about how much I enjoyed it.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4) Value/Usefulness</th>
<th>5) Pressure/Tension</th>
<th>6) Relatedness</th>
</tr>
</thead>
<tbody>
<tr>
<td>• I believe this activity could be of some value to me.</td>
<td>• I did not feel nervous at all while doing this. (R)</td>
<td>• I felt really distant to my teammate. (R)</td>
</tr>
<tr>
<td>• I think that doing this activity is useful for promoting my interest in learning engineering.</td>
<td>• I felt very tense while doing this activity.</td>
<td>• I really doubt that my teammate and I would ever be friends. (R)</td>
</tr>
<tr>
<td>• I think this is important to do because it shows me how to build, test and package a prototype of digital electronic project.</td>
<td>• I was very relaxed in doing these. (R)</td>
<td>• I felt like I could really trust my teammate.</td>
</tr>
<tr>
<td>• I would be willing to do this again because it has some value to me.</td>
<td>• I was anxious while working on this task.</td>
<td>• I’d like a chance to interact with my teammate more often.</td>
</tr>
<tr>
<td>• I think doing this activity could help me to sharpen my thinking and problem solving skills in group works and presentation.</td>
<td>• I felt pressured while doing these.</td>
<td>• I’d really prefer not to interact with my teammate in the future. (R)</td>
</tr>
<tr>
<td>• I believe doing this activity could be beneficial to me.</td>
<td></td>
<td>• I don’t feel like I could really trust my teammate. (R)</td>
</tr>
<tr>
<td>• I think this is an important activity.</td>
<td></td>
<td>• It is likely that my teammate and I could become friends if we interacted a lot.</td>
</tr>
</tbody>
</table>

Note: The items marked with (R) are negative statements. To calculate the item score, subtract the item response from 8.
Of the seven subscales, six were determined to be relevant to our investigation. We exclude the subscale on perceived choice as all the learning tasks and activities were compulsory for all students taking the module. The six subscales with a short description on the dimension that they measure are listed below, and the questionnaire items are listed in Table 3:

1) Interest/Enjoyment – students who enjoy doing an activity are more motivated;
2) Perceived Competence – students who perceive themselves competent in doing an activity are more motivated;
3) Effort/Importance – the amount of effort a student puts in for an activity or the level of importance a student assigns to an activity is considered highly relevant to his/her level of motivation;
4) Value/Usefulness – an aspect that is related to one’s internalization of an experience;
5) Pressure/Tension – students who experience pressure or tension in doing an activity are less motivated;
6) Relatedness – an aspect that is related to interpersonal interactions or friendship formation during an activity.

The items were randomized in their sequence before they were presented to the students in the form of a survey. The entire cohort of year-one DTMT students (20 students) took part in the survey at the end of the semester. At the same time, another 14 students having similar academic profiles as the 20 DTMT students were selected from the Diploma in Electronics, Computer and Communications Engineering (DECC) course to participate in the same survey. These 14 students from the DECC learned DE in the traditional way of Lecture-Tutorial-Practical delivery.

RESULTS

Quantitative Study

The results of the survey are summarized in Table 4. The effect size of each of the six IMI subscales between the two groups of students was then computed based on Cohen’s d criteria (“Effect Size (ES)”, 1996). The outcomes are shown in Table 5.

The results from this investigation using IMI indicate a significant difference in students’ self-report of the interest/enjoyment subscale and the perceived competence subscale. There is evidence that DTMT students had higher interest and enjoyed learning DE through the “learning-by-doing” approach, as compared to students from the DECC who learned the subject in the traditional way. There is also evidence that students from the DTMT perceived themselves to be more competent in the DE as compared to students from the DECC. Furthermore, DTMT students appreciated the value or usefulness of the module more while experiencing less pressure or tension in class. These quantitative results reinforced the recognition from past surveys and observations that the “learning-by-doing” approach is effective in enhancing students’ motivation in learning DE.

Though the results show only a small difference between DTMT students and DECC students on the relatedness subscale, the average rating of this subscale was the highest for DTMT students among the six subscales. This shows that they were experiencing supportive relations with their teammates while they were working on the group project. As for the results on the effort/importance subscale, the difference is insignificant. It was initially worried that the students might place less importance on this module, as it does not require the
students to sit for formal examination at the end of the semester. Hence, the results were encouraging as they only indicated a trivial effect.

Table 4. Results of Survey Using IMI

<table>
<thead>
<tr>
<th>IMI Subscales</th>
<th>DTMT Students (20)</th>
<th>DECC Students (14)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average Rating</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>Interest/Enjoyment</td>
<td>4.99</td>
<td>0.70</td>
</tr>
<tr>
<td>Perceived Competence</td>
<td>4.65</td>
<td>0.86</td>
</tr>
<tr>
<td>Effort/Importance</td>
<td>4.72</td>
<td>1.30</td>
</tr>
<tr>
<td>Value/Usefulness</td>
<td>5.22</td>
<td>0.73</td>
</tr>
<tr>
<td>Pressure/Tension</td>
<td>3.45</td>
<td>0.96</td>
</tr>
<tr>
<td>Relatedness</td>
<td>5.26</td>
<td>0.97</td>
</tr>
</tbody>
</table>

Table 5. Effect Size Computations Based on Cohen’s d Criteria

<table>
<thead>
<tr>
<th>IMI Subscales</th>
<th>Cohen’s d</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest/Enjoyment</td>
<td>0.94</td>
<td>Large</td>
</tr>
<tr>
<td>Perceived Competence</td>
<td>0.79</td>
<td>Large</td>
</tr>
<tr>
<td>Effort/Importance</td>
<td>-0.06</td>
<td>Very Small</td>
</tr>
<tr>
<td>Value/Usefulness</td>
<td>0.7</td>
<td>Medium</td>
</tr>
<tr>
<td>Pressure/Tension</td>
<td>-0.54</td>
<td>Medium</td>
</tr>
<tr>
<td>Relatedness</td>
<td>0.24</td>
<td>Small</td>
</tr>
</tbody>
</table>

Qualitative Study

Six DTMT students were selected for interviews. Through these interviews, their views on the “learning-by-doing” approach adopted in the module were further revealed. The group project on prototype design and the final project exhibition were mentioned by the interviewees as the most interesting part of the module. One student specifically pointed out that her interest in engineering actually improved after knowing the applications of digital circuits through the module. The interviewees also enjoyed working on project in teams, and reflected that they valued the usefulness of personal and interpersonal communication skills they practised through the group project discussion and presentation.

Though the interviewees appreciated the usefulness of technical troubleshooting skills they learned through the individual project, they also commented that the challenges they faced during the troubleshooting process had somewhat killed their interest in learning the subject to a certain degree. While the quantitative results show a reduction on the IMI subscale of pressure/tension in general for DTMT students, the interviewees reflected it was during this troubleshooting stage that they experienced the most pressure. The students’ confidence level of their technical skills might have suffered from failures experienced during this troubleshooting stage, as they commented that they were more confident in their soft skills than in their technical skills.

When the interviewees were asked if they preferred the “learning-by-doing” approach to the traditional way, it was interesting to note that the students with prior hands-on learning

\[ A \text{ Cohen's } d = 0.2 \text{ is considered a 'small' effect size, 0.5 represents a 'medium' effect size and 0.8 a 'large' effect size. A 'small' and 'large' effect size implies the difference between the two sample sizes is trivial and substantial respectively.}\]
experience in the secondary school agreed that the approach adopted in the module was more effective for their learning, whereas those without prior hands-on learning experience in the secondary school opined that they might learn better through the traditional way.

Lastly, the interviewees also revealed that the personality of the lecturer played a key factor in how they placed importance to a module. It confirms our belief that the lecturer plays an important role in triggering the students’ interest in learning a module. This reaffirms the findings of research studies on how teacher personality would determine teacher-student interpersonal behaviour and its effect on student learning outcomes (Fisher et al., 1998).

CONCLUSIONS

The adoption of the “learning-by-doing” approach to teach DE to the first-year students has been a successful effort. The surveys and interviews conducted with the students affirm the effectiveness of this approach in enhancing the students’ motivation in learning DE, as compared to those students who learn DE in the traditional way. However, the sample size of this study was limited by the small cohort size of DTMT students. As revealed by the interviews with selected DTMT students, there are other factors that might impose limitations on this investigation, which include the proportion of students with prior hands-on learning experience in the comparison group, and the personality of the lecturer teaching the comparison group. Hence, moving forward, the study on the effect of this “learning-by-doing” approach on students’ motivation will be extended to a larger scale that covers more modules and courses in SEG.

With the encouraging results from this small-scale investigation with the DTMT, more lecturers are encouraged to adopt the “learning-by-doing” approach in their modules. Nonetheless, we acknowledge that there are some challenges in adopting this approach. As pointed out by the interviewees in this study, the lecturer would have to address the difference in the students’ prior knowledge. More learning activities are to be put in place to scaffold the students in learning the technical troubleshooting skills. Providing some early success opportunities would motivate the students in overcoming the setbacks that they are likely to face in the application phase of their experiential learning (Ambrose et al., 2010). Feedback from the students hence plays an important part in helping the lecturers to fine-tune the processes and learning activities to ensure that the implementation of the “learning-by-doing” is sustainable, and the students gain fruitful learning experience from this approach.

REFERENCES


BIOGRAPHICAL INFORMATION

Goh Eng Siong is a Senior Lecturer in the IC Design Centre (Mixed Signal Section) at the School of Engineering, Nanyang Polytechnic, Singapore. He is the Module Coordinator of Digital Electronics module in the Diploma in Electronics, Computer and Communications Engineering course. He is also a key member of the Academic Development Work Group at the School of Engineering.

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AN INTEGRATED CURRICULUM APPROACH TO DEVELOP INDUSTRY-READY BIOMEDICAL ENGINEERING GRADUATES

Kallen Chong, Ong Hui Yng, Liang Kwong, Choo Keng Wah

School of Engineering, Nanyang Polytechnic, Singapore

ABSTRACT

This paper presents the new applied learning track for Quality and Processes in Biomedical Manufacturing that is built specifically on CDIO Standard 3 – Integrated Curriculum. The key feature of this new curriculum is the progressive building up of students’ knowledge and working skills via contextual learning and a 24-week structured internship. The paper shares our experience in designing the integrated curriculum and developing the 24-week structured internship program with partnership from the biomedical manufacturing sector. Results of the implementation and measures to address the gaps identified during the implementation are also discussed.

KEYWORDS

Integrated and experiential learning, integrated curriculum, competency-based assessment, contextualized learning, Biomedical Engineering, Standards: 3, 7

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 Biomedical Engineering is a course; Biomedical Project is a module.

INTRODUCTION

The biomedical manufacturing sector in Singapore is growing fast, supported by output expansions in both the pharmaceutical and medical technology segments (Ministry of Trade and Industry Singapore, 2016). The pharmaceutical segment was boosted by the increase in production of existing and newly-introduced active pharmaceuticals ingredients and biological products. The medical technology segment, on the other hand, continued to benefit from robust export demand for medical devices. The demand for industry-ready workforce is set to grow in this sector.

In response to this demand, the Diploma in Biomedical Engineering (DBE) at Nanyang Polytechnic offered a new applied learning track in 2014 focusing on quality management and manufacturing processes in biomedical industry. The new applied learning track was developed using the CDIO principles and guidelines (Crawley, Malmqvist, Östlund, & Brodeur, 2007) and the contextual teaching and learning pedagogical approach (Berns & Erickson, 2001). In particular, the curriculum was designed using CDIO Standard 3 – Integrated Curriculum to better reflect the multidisciplinary nature of biomedical engineering.
The focus was on providing an integrated learning experiences for students to take an active role in their learning and discover for themselves the relevance of training to their future career needs.

In this paper, we first share the environment scan that was carried out to gather the training needs, then we present the process of designing the integrated curriculum and some examples of those integrated learning opportunities. Finally we present the results of the implementation and discuss measures to address the gaps identified during the implementation.

INTEGRATED CURRICULUM DESIGN

Relevance of DBE Curriculum

The first step was to perform an environmental scan in the current biomedical industry landscape and manpower needs in Singapore. This was done by conducting surveys with companies and alumni, and interviews with faculty and Singapore government agencies. The outcomes of the environmental scan were summarised as follows:

- Industry feedback had indicated that the current DBE curriculum remained relevant to the biomedical industry for skillsets in the areas of medical device design & development, and regulatory compliance. However, skillsets to support latest biomedical manufacturing technology, process validation, automation & control could be further enhanced into the curriculum.
- Information gathered from interviews with government agencies and studies on the biomedical landscape also pointed to the emerging manpower needs on skillsets to support the governments push towards higher productivity and high-value added manufacturing in the biomedical industry.
- Feedback received from the alumni showed that the current curriculum had equipped them with strong foundation knowledge and skills in medical device design and regulatory compliance. However, more employment opportunities were found in the manufacturing sector which required different skillsets in manufacturing technology, process control and quality compliance.
- Feedback received from faculty members, through interaction with industry partners and literature review, showed that students should be prepared to manage the changing technology in biomedical manufacturing activities such as the use of robotic automation in reducing reliance no human labour. In addition, students should be introduced to the biomedical industry landscape in Singapore starting from Year 1 so that they could have a head start for their future career planning.

These feedbacks served as the basis for the review and enhancement to the existing DBE curriculum.

Integrated Curriculum

The key strategy in designing this new applied learning track was based on the CDIO Standard 3 – Integrated Curriculum. In another words, the curriculum should be designed with mutually supporting disciplinary modules, and with an explicit plan to integrate personal, interpersonal, and product, process, and system building skills.
Following the design process recommended by Malmqvist and his co-workers (2006), we defined the objective of the applied learning track in quality management & biomedical manufacturing technology (see Figure 1). The objective of the new applied learning track is to train a pool of graduates who are technically competent, professionally proficient and socially responsible in quality management, regulatory compliance and manufacturing processes in the biomedical sector. This was followed by an iterative process of developing the learning outcomes, aligning the learning outcomes, designing the learning activities and applying the assessment methods of the modules offered in this track in an integrated manner to meet the biomedical sector’s needs.

**Figure 1. An integrated Applied Learning Track Design Process**

This process led us to design a new module in year 1 to introduce students to the biomedical manufacturing processes. This was followed by another new module in year 2 to strengthen students’ knowledge and skills in good manufacturing practices. Finally, specialised modules were introduced in year 3 to allow students to deepen their knowledge and skills, as well as gain working experience through a 24-week structured internship program. The old and the revised DBE integrated curriculum maps with the new applied learning track are shown in Figure 2a and 2b respectively.

**Figure 2a. The Old Integrated Curriculum Map of the Diploma in Biomedical Engineering (biomedical manufacturing related modules are highlighted in red boxes)**
Figure 2b. The Revised Integrated Curriculum Map of the Diploma in Biomedical Engineering (the new applied learning track are highlighted in grey boxes)

**Integrated Learning Experiences**

**Training Facilities for Integrated Learning Activities**

To provide our year 1 and year 2 DBE students with contextualised learning experience and hands-on training in a real-life good manufacturing practice working environment, a secondary pharmaceutical teaching facility was set up to train them for the biomedical manufacturing industry. This facility, as shown in Figure 3, trained students on industry-related equipment and processes. It allowed students to acquire skills and knowledge in application of good manufacturing practice which included manufacturing operations, documentation and requirement of production batch records, cleanroom monitoring, clean utilities, validation and facility management.

Figure 3. Secondary pharmaceutical teaching facility for integrated learning experience
Learning Journey

To further enhance the learning experience, learning journeys were organized to related biomedical industries for year 2 and year 3 DBE students (see Figure 4). Through these learning journeys, students were exposed to the real-life working environment in the industry and had the opportunities to explore the requirements of various job functions available for biomedical engineering graduates. Through reflection on these learning journeys and applying the personal career strategy, students were able to recognize their strengths, interests, personality and values that influenced their education and career decision making.

Figure 4. Industry experiential learning trip to Novartis Singapore & Alcon Singapore

Structured Internship Program

Structured internship program is a program that NYP co-designs and develops with our industry partners to meet the training need of an industry sector. This well-structured on-the-job or work-based learning program aims to provide a real-life work environment and facilitate a structured and integrated learning experiences for our Year 3 students before they graduate and join the work force. Through the structured internship program, students further deepen their competencies for occupational skills, transferable workplace skills and personal effectiveness skills. With this structured internship program put in place, our DBE students were able to carry out internships in several related quality and process management departments within the biomedical manufacturing industry and gained valuable experience. Two examples of the structure internship program in a production department of a biopharmaceutical company and a quality control department of a medical device company can be found in Annex 1.

RESULTS AND DISCUSSION

Since the launch of the new applied learning track in the Quality Management & Biomedical Manufacturing Technology in 2014, a total of 31 DBE students completed this applied learning track and the structured internship program in various job functions in the biomedical companies. The effectiveness of the integrated curriculum in this applied learning track was measured through the feedback received from the industry partners on students’ performance in the internship program and the graduate employment rate.

Positive comments were received from the industry partners on the students’ performance. For examples, it was highlighted that our students demonstrated an excellent attitude in approaching the tasks assigned to them and they took the initiative to contribute new ideas and gave their best efforts to all tasks that were assigned to them. It was also highlighted that our students were competent in performing good manufacturing practice checks and
review, and they were able to complete their assignment prior to the given deadlines with high quality outcomes.

From the graduate employment survey that was conducted annually by the Singapore’s Ministry of Education, the employment rate for students who graduated from the DBE has improved by 12.5% in 2016 when compared with the employment rate obtained in 2013. In the same survey, students also reflected positively to the revised integrated curriculum and more students (an increment of 50% from 2013) found the training to be relevant to the job they were doing.

CONCLUSION

The revised integrated curriculum where an applied learning track was created to meet the need of the biomedical manufacturing industry has effectively met our curriculum review objectives as well as the intended learning outcomes for our biomedical engineering students. Graduate employment survey has improved significantly and the industries recognise that our graduates are more industry-ready and confident in facing the complex, highly regulated and challenging biomedical manufacturing industry.

However, through interaction with recent graduates and industry partners, there are still gaps in our graduates’ skill sets. They expressed that extended period of structured internship program would be needed to deepen the skills that were required for students contribute efficiently in a broad range of products and processes in this industry. To address these gaps, plans have been put in place in developing a 12-month integrated work-study program for graduates who wish to develop their careers in the biomedical manufacturing sector. The proposed work-study program will comprise an on-campus study, self-directed e-Learning as well as the on-the-job training components. This program will allow the students to further acquire the needed domain-specific knowledge and deepen their skills and experience in this industry.

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BIOGRAPHICAL INFORMATION

Kallen Chong is a Senior Lecturer in the School of Engineering, Nanyang Polytechnic. She leads the establishment of enhanced internship with biomedical science and engineering industry. Kallen held several non-academic portfolios such as Quality Manager for an ISO17025 accredited laboratory and capital project leader in setting up a GMP pharmaceutical pilot plant training facility at NYP. Prior to joining NYP, Kallen worked in chemical and pharmaceutical industry in the functions of technical development and quality management for about 10 years.

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Liang Kwong is a Senior Lecturer in the School of Engineering, Nanyang Polytechnic. He graduated with a Master of Science (MicroSys & Nano) and Mater of Science (Statistics). He is actively involved in industry project development and management of internship program for DBE. Liang Kwong also conducts CET courses in Precision Engineering at Nanyang Polytechnic.

Dr Choo Keng Wah is a Deputy Director in the School of Engineering, Nanyang Polytechnic. He is actively involved in industry project development and management, biomedical research and development projects, protection and commercialization of IPs, engineering education benchmarking, education quality assurance and accreditation.

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Annex 1: Examples of structured internship program

a) Blueprint for Structured Internship Program in the production department of a biopharmaceutical company

<table>
<thead>
<tr>
<th>Main Task</th>
<th>Task Elements</th>
<th>Key Points</th>
<th>Task Standards</th>
<th>Skills &amp; Knowledge</th>
<th>Training Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good Manufacturing Practice (GMP)</td>
<td>Introduction to current Good Manufacturing Practice (cGMP)</td>
<td>Understand the fundamentals of GMP &amp; its consequences if not followed</td>
<td>Pass the cGMP test</td>
<td>GMP trained</td>
<td>Part 1 – Practicum. Trainees learn on the job</td>
</tr>
<tr>
<td></td>
<td>Introduction to Good Distribution Practice (GDP)</td>
<td>Understand GDP and the meaning of signature and understand the importance of Data Integrity</td>
<td>Pass the GDP test</td>
<td>GDP trained</td>
<td>Part 2 – Supervision. Trainees expected to carry out tasks under direct supervision</td>
</tr>
<tr>
<td></td>
<td>Read &amp; Understand Zoning Classification in BiopharmOps</td>
<td>Understand zoning concepts and its rationale</td>
<td>Ability to perform zoning correctly</td>
<td>Ability to perform material flow and personnel flow correctly</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Read &amp; Understand GMP Procedures</td>
<td>Ability to follow zoning procedures</td>
<td>Fulfilled basic requirements to work in a clean room environment</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Read &amp; Understand Material Flow &amp; Personnel Flow in Process Unit</td>
<td>Understand the basics of facility flow</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

b) Blueprint for Structured Internship Program in a quality department of a medical device company

<table>
<thead>
<tr>
<th>JOB TITLE</th>
<th>UNIT</th>
<th>DEPARTMENT</th>
<th>TOTAL TASKS</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality Lab Technician</td>
<td>GC Lab</td>
<td>Quality</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SN</th>
<th>Main Task</th>
<th>Task Elements</th>
<th>Task Standards</th>
<th>Skills &amp; Knowledge</th>
<th>Training Guidelines</th>
<th>COT Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Complete the new hire orientation program</td>
<td>a) Understand company business activities on site</td>
<td>Test result shall meet acceptance criteria in raw material specifications for reference standards</td>
<td>Knowledge: GMP, GDP, GLP</td>
<td>Info sharing, Demonstration</td>
<td>5 work-days</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Comply with WSH policy on site</td>
<td></td>
<td>Skills: Compliance to company HR policy, QMS &amp; WSH</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>c) Understand company HR Policy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>d) Comply with Quality Management System (QMS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Perform at least three raw material test methods as per SOP using reference standards within 8 weeks</td>
<td>a) Analyse assay of process nitrogen according to SOP-QC-018</td>
<td>Test result shall meet acceptance criteria in raw material specifications for reference standards</td>
<td>Knowledge: GMP, GDP, GLP, Biosafety</td>
<td>Demonstration, Practical (on the job)</td>
<td>15 work-days</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) Analyse water content of PVA according to SOP-QC-023</td>
<td></td>
<td>Skills: Testing according to SOP, Aseptic sampling, Instruments</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>c) Test microbial count of WFI according to SOP-QC-100</td>
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<td></td>
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</tr>
<tr>
<td>3</td>
<td>Perform at least 10 quality test records checking according to GDP requirements within 4 weeks</td>
<td>a) Checking quality test record for compliance to GDP requirements</td>
<td>Passing relevant SOP competency assessment</td>
<td>Knowledge: GMP, GDP</td>
<td>Reading of SOP on document Control (SSL, via company training portal)</td>
<td>10 work-days</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Meeting GDP standard</td>
<td>Skills: Document checking according to GDP requirements, Filling of Deviation Form</td>
<td></td>
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</table>
TECHNOLOGY AND TEACHING IN ENGINEERING EDUCATION:
A BLENDED COURSE FOR FACULTY

M. Cleveland-Innes, S. Stenbom, S. Gauvreau
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ABSTRACT
This paper provides a case study description of a teaching development course for engineering faculty. Findings indicate that faculty engaging in a blended course about online and blended learning perceive significant benefits to the learning design. Perceived benefits far outweighed concerns about this alternative to classroom teaching alone.

KEYWORDS
Engineering education, higher education, teaching, learning, faculty roles, Standards: 8, 9, 10, 12

INTRODUCTION
During the last decades, an explosion of digital tools to support daily life have been introduced. Online and blended learning is one such tool; it offers the opportunity to support higher education through web-based content delivery and interaction. But the success of online and blended learning delivery is dependent on the knowledge and expertise held by faculty about this new way of teaching and learning.

This paper reports results from an exploratory case study of a teaching development course at KTH Royal Institute of Technology in Stockholm, Sweden. This research method was chosen to "allow the research community to be able to better address questions around key engineering education challenges ..." (Case & Light, 2011, p. 186.). The challenge addressed through this research refers to the larger education reform movement in higher education.

Findings indicate a notable range of responses from faculty to the design and use of blended learning but a definite interest in the use of technology for learning. This paper includes 1) a description of the context in which the course is offered to faculty, 2) information about how this blended course about blended teaching and learning was created, and 3) conceptual themes that emerged from analysis of discussion forum posts about the use of blended communities’ of inquiry for engineering education.
BACKGROUND INFORMATION

In the transition from traditional, lecture-based, classroom teaching is a silent conundrum; teachers using this ‘tell them and test them’ method of teaching require little or no expertise in instructional design, learning theory, teaching strategies beyond the lecture, or learning assessment. Using online and blended learning in teaching includes “the development of teaching materials, the instructional design and the pedagogy of the delivery including assessment strategy.” (Lucke et al., 2016, p. 3). More than just a move to using the technology, online and blended learning requires new ways of designing courses and teaching. While there are great advantages to doing this, the required time and expertise make it more difficult for faculty to be exemplars in both teaching and research (Fairweather, 2002). Support, and training, is one way to address this difficulty.

As an opportunity for faculty at KTH Royal Institute of Technology to develop skill and expertise in online and blended teaching, we created a course titled Teaching Strategies and Design for Online and Blended Learning. The course is equivalent to two weeks of full-time study. KTH, and other higher education institutions in Sweden, require at least ten weeks of full-time study in the field of teaching and learning in order to be tenured. For a copy of the course syllabus in English, see https://www.kth.se/student/kurser/kurs/LH218V?l=en.

KTH was founded in 1827 as the premier technological school in Sweden, offering subjects in science with a practical, professional focus. KTH is Sweden’s oldest and largest technical university. Approximately one-third of Sweden’s technical research and engineering education capacity at university level is provided by KTH. Currently, 13,400 first and second level students and 1,900 doctoral students study at KTH.

KTH has remained a leading-edge institution since its inception. Recently, KTH created a Vision 2027 strategy: “Information technology as an integral part of everyday life will have altered conditions for university studies fundamentally by 2027. Competition is becoming global when courses, to an ever larger extent, are offered via cloud computing networks and when teaching materials are becoming omnipresent. E-education is a self-evident part of competitive bids for university studies. There is a special challenge in acquiring and maintaining a leading position in both ICT research and e-education.”

The teaching development initiative reported here responds to the above vision and to two calls for change in higher education. The first is the need to improve expertise on teaching and learning among faculty in higher education (Rienties, Brouwer, & Lygo-Baker, 2013). The second, as indicated in KTH’s vision, is to create expertise among faculty regarding e-education, and the use of ICTs for teaching and learning.

LITERATURE REVIEW

Engineering education exists within the higher education enterprise, where demands for change impact all disciplines, fields of study, and programs. This literature review begins with a review of the need for change specifically in teaching and learning in higher education. Training in online and blended learning represents a significant form of faculty development for teaching and learning. This is also outlined below. Review of specific research in online engineering education completes this segment of this paper.
Over the last two decades, "... classroom teaching and course materials (have become) more sophisticated and complex in ways that translate into new forms of faculty work...such new forms are not replacing old ones, but instead are layered on top of them, making for more work" (Rhoades. 2000, p. 38). This layering rests on the top of a spotty foundation of teaching and learning expertise on the part of faculty. Making changes in one’s practice is difficult at any time but is a greater challenge when there is little foundation on which to assimilate new ways of doing things. By the time a faculty appointment is offered, most academics have a promising record of expertise in research. And while some new faculty will have teaching experience in the lecture hall, too many will enter the academy without the fundamental pedagogical knowledge required for good teaching. The general assumption is that good teaching ‘comes naturally’ (Beckerman, 2010). Recognizing that teaching does not always come naturally for many faculty, institutions of higher education now offer courses to improve teaching quality by increasing pedagogical expertise. This paper reports the faculty experience in such a course.

This course served as an education experience for KTH faculty who are interested in online and blended learning design. It was created with reference to multiple learning theories and delivery opportunities. First, the textbook and the orientation to design and delivery in this course are based on the online Community of Inquiry model (Garrison, Anderson & Archer, 2000; Vaughan, Cleveland-Innes, & Garrison, 2013). The model rests on Dewey’s (1910) views on experiential learning and is constructivist in nature. The roles of instructor and student are transformed by three overlapping presences: cognitive, social, and teaching presence. Social presence emerges through the ability of participants to connect with the others in the community, the opportunity, through facilitation, to communicate purposefully in a trusting environment, and to develop relationships by projecting their individual personalities and acknowledging others who are doing the same. Cognitive presence describes the degree to which learners are able to construct and confirm meaning through sustained reflection and discourse. The third and central organizing element is teaching presence. Teaching presence is available to the instructor and the students. It is created through the design, facilitation, and direction of cognitive and social processes such that personally meaningful and educationally worthwhile learning outcomes can be realized.

A blended Community of Inquiry is a method of course delivery guided by the “thoughtful integration of classroom face-to-face learning experiences with online learning experiences” (Garrison & Kanuka, 2004, p. 96). As such, blended learning can be integrated into all parts of the CDIO syllabus (CDIO Syllabus 2.0, n.d). Guided by the Community of Inquiry model, the disciplinary knowledge and reasoning as well as personal and professional skills and attributes are manifested by the individual’s practical inquiry that is structured as cognitive presence. Interpersonal skills: teamwork and communication is embedded in the collaborative and constructivist approach to learning that is manifested in the Community of Inquiry and can particularly be visualized by the open communication, and group cohesion of social presence. The processes of conceiving, designing, implementing and operating systems in an educational context can be of the design and organization of teaching presence. Here, it is important to note that the element of teaching presence is the responsibility of the instructor(s) but can be displayed by any participant as they understand, monitor, and regulate their own or peer-students learning. Collaboration is most important.

Although time consuming, collaborative instruction is central to the benefits of online teaching and learning. The individualization of communications, and the role of instructor as a facilitator of student participation and learning, add to the instructor workload when teaching online (Davidson-Shivers, 2009). In balance, a central teaching advantage of online delivery
is the opportunity to better engage learners in more active and collaborative educational experiences. Tomei (2004) proposes that online student expectations for on-demand, continuous feedback necessitates smaller class sizes relative to those in traditional classroom instruction. Reducing class size is one option available to compensate for the imposition of time online teaching will impose; a value added in any delivery method. For Tomei then, the 40-40-20 formula for allocating faculty time (40 percent teaching, 40 percent research, and 20 percent service) suggested by the American Association of University Professors (AAUP) must be reshaped for faculty teaching in an online environment. Given this, it is unrealistic to assume that emerging Internet technologies will transform teaching practices in higher education without changing how faculty work. (Yick, Patrick, & Costin, 2005).

METHODS

Case study research is an emerging methodology in engineering education (Case & Light, 2011). It is an acceptable method, particularly in education research, where the research purpose is to explore, describe, or explain findings emerging in a bounded but complex environment. This exploratory study is a test of the theoretical premise that experience in an online course will provide faculty the opportunity to evaluate the value of such. In this case, faculty experience an online and blended learning environment to learn about teaching in such an environment.

This experience was offered to teachers at KTH through the course Teaching Strategies and Design for Online and Blended Learning. The theoretical part of the course is from the extensively researched theory of an online Community of Inquiry (Vaughan, Cleveland-Innes, & Garrison, 2013). This theoretical framework represents a process of creating a deep and meaningful (collaborative-constructivist) learning experience through the development of three interdependent elements - social, cognitive and teaching presence. In agreement with Lucke, Brodie, L., Brodie, I., & Rouvrais (2016) and Norrman, Bienkowska, Moberg, & Frankelius (2014), well-designed online and blended learning can support CDIO-based engineering education.

Design opportunities were offered in the application part of the course where participants designed a module of online and blended learning. The expectation, beyond the course requirements themselves, is that the module will be implemented in a course of the participants’ field. In addition to experiencing online and blended learning, application practice allowed participants to test and evaluate tools and techniques often used in online and blended education. The tools are chosen among those which are supported at KTH.

Participants in this study hold positions related to instruction at KTH. Participation is voluntary. Credits received for taking the course satisfy pedagogical training requirements; in order to be appointed as associate or full professor at KTH, faculty must have 10 weeks of courses in teaching and learning in higher education. The course ran once per year in each year 2013, 2014, and 2015.

For this study, data were drawn from discussion posts in Week 2 of the course that focused on the conceptual framework of the Community of Inquiry model for online and blended learning in engineering education. Participants were asked to read Teaching In Blended Learning Environments by Vaughan, Cleveland-Innes & Garrison (2013) and answered questions on 1) their perceptions of the model, 2) which activities work best for teaching
face-to-face versus online, and 3) how they could use each aspect of teaching presence in support of teaching principles.

As the data review was based on concepts outlined in the Community of Inquiry theoretical framework, a deductive method of data coding was employed. Two coders identified key concepts they believe would be valuable when analyzing the data. A final structure was then negotiated based on the two lists. Coding proceeded separately by each coder and an inter-rater reliability score will be assessed and reported. For dialogue that did not fit within the final coding structure, we instead used inductive coding. For this section of the data, a process of open or free coding followed by axial or verification coding, and finally confirmatory coding was employed (Neuman, 2011).

A total of 52 university employees took this course over three years. The distribution of respondents according to schools is outlined in Table 1. below. Table 2. outlines distribution across academic rank.

<table>
<thead>
<tr>
<th>KTH School</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>Grand Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architecture and the Built Environment</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Biotechnology</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Chemical Science and Engineering</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Computer Science and Communication</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Education and Communication in Engineering</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Electrical Engineering</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Industrial Engineering and Management</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Information and Communication Technology</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Engineering Sciences</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Technology and Health</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>External</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td><strong>12</strong></td>
<td><strong>21</strong></td>
<td><strong>19</strong></td>
<td><strong>52</strong></td>
</tr>
</tbody>
</table>
Table 2. Participants by rank

<table>
<thead>
<tr>
<th>Title</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assistant Professor</td>
<td>9</td>
</tr>
<tr>
<td>Associate Professor</td>
<td>8</td>
</tr>
<tr>
<td>Lecturer</td>
<td>12</td>
</tr>
<tr>
<td>Other</td>
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</tr>
<tr>
<td>Ph.D. student</td>
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</tr>
<tr>
<td>Postdoc</td>
<td>1</td>
</tr>
<tr>
<td>Researcher</td>
<td>14</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td><strong>52</strong></td>
</tr>
</tbody>
</table>

FINDINGS

Four themes emerged and were verified through sequential coding processes. Over three course offerings a total of 18,243 words made up the forum discussions about blended and online learning (Week 2). Any text from facilitators, or about general course logistics, was removed.

The message was the unit of analysis. Word counts are used as a baseline and a way to view amounts for comparison. For this discussion, 9% of words in the total word count of all three semesters focused on the topic of challenges perceived or resistance to the use of online and blended learning. The remainder were divided into 15% for general learning design, 48% for perceived benefits of blended and online learning, and 28% for ideas for making changes in current teaching methods and/or learning design through online and blended learning. Below is a description of each theme with examples of coded messages for each. Figure 1. graphically presents the relative amounts of different themes.

Challenges/Resistance (**9%**) refers to messages about reasons to not consider or adopt blended or online learning in engineering education. Messages referred to issues such as technology access, student readiness, and time constraints. Examples are:

- “…from the perspective of student learning, a lot of one-to-one instruction is the best.”
- “If you just open a discussion forum … the students are most probably not going to use it for internal discussions.”

General learning design (**15%**) is a theme which captures more general statements about learning design in any delivery mode. Discussing opportunities in online and blended learning provides a rare opportunity to discuss learning, course design, and teaching in general. Examples are:

- “… everything you do in the classroom (or in the online classroom) has an element of design and facilitation in it.”
- “I think there should be more focus on the social cognition and learning, where students learn in a social environment, where they both learn and exchange from each other to a higher degree.”
Benefits of blended/online learning (48%) identifies messages about the topic of benefits of blended and online learning. This includes reflections about the meaning of different aspects of blended and online learning and, once understood, how it might be used. Examples are:

- “Empowering teaching presence to be more efficient in blended methods, is an ability to communicate, give feedback between lessons, update assignment.”
- “First I must say that I find this discussion forum much more rewarding for my learning than I thought! It clearly gives me some new perspectives on the reading material.”

Ideas for change (28%) includes all messages referring to specific changes faculty were considering in reference to their teaching practice or their courses. Examples are:

- “… use software that is not too much of an obstacle is a first step of course, and to invite any novices to learn tips and tricks from experienced students.”
- “…make sure that the online CoI is somewhat wider as compared to the group in classroom … by making sure that experts from other universities/industry (are included).”

Our purpose was to identify faculty responses to the idea of using a blended learning design as a key experiential learning strategy while they were engaged in such an environment. Discussion forum messages clarify that participants did engage in the learning experience and, according to some participants, found the unique learning experience itself valuable, as well as the content.

The community of inquiry that emerged during the course provided a rich environment for faculty discussion. It is possible that this experience explains the large proportion of postings that focused on the benefits of online and blended learning. Faculty both experienced and
studied the components of online and blended learning, allowing for thoughtful review and critique of such an environment. The opportunity to explore new ideas about teaching and learning and integrate them, first conceptually through discussion and then in practice through the application exercise, followed the conceptual requirements for a meaningful learning experience as described in the online Community of Inquiry theoretical framework.

Ensuring educationally worthwhile outcomes in engineering education using CDIO requires pedagogical methods that are instructional themselves. While there is no clear narrative yet on how to ensure improved pedagogy in engineering education, the use of blended and online learning has sparked much talk about pedagogy. According to Yigit, Koyun, Yuksel, & Cankaya (2014), “thinking abilities of students who enrolled in the Algorithm and Programming course in blended and traditional education are close” (p. 1). However, learning that includes the pedagogy of web-based engagement allows students to develop more skills related learner independence; skills that transfer for the support of lifelong learning.

Beyond benefits to students, blended learning is “successful in providing an efficient and effective learning experience to both students and faculty” (Shambhavi & Babu, 2015, p. 313). In addition, online and blended learning could be a remedy for some of the challenges in engineering education, where there is a call to “adopt strategies and tools for using a multiple perspectives approach to better understand complex engineering education problems” (Adams, Evangelou, English, de Figueiredo, Mousoulides, Pawley, & Wilson, 2011, p. 48). Engaging engineering faculty in review and discussion about new pedagogies like online and blended learning, pedagogies such as the Community of Inquiry theoretical framework, can provide great benefit to engineering education overall.

CONCLUSIONS

Online and blended learning represents a new wave of teaching and learning which can support teaching quality in general and the implementation of the CDIO standards. (Lucke, Brodie, L., Brodie, I., & Rouvrais, 2016). Improving quality of instruction is a common topic in discussions about higher education reform. Online and blended learning makes good use of available technologies and prepares students for more learner independence, lifelong learning, and competence in the digital world (Duderstat, 2009; Keller, 2008). Integrating information and communication technologies, online learning creates both independence and interaction enabling the creation of learning communities. Online and blended learning has been utilized extensively to enhance classroom learning as well as to increase access to educational experiences at a distance.

To recap, analysis was completed and reported previously on only one section of the course (Cleveland-Innes, Stenbom, & Hrastinski, 2015). Reported here are preliminary findings from analysis of the combined forum discussion data set, Week 2. The entire data set is very large, capturing 5 weeks of forum discussions from 52 participants. Future research will identify how perspectives about blended and online learning change over the span of the course experience.

Two key findings stand out at this early point in our analysis. First, the opportunity to discuss learning design and teaching is a unique and welcome opportunity for faculty and, with the addition of text-based discussion forums between classroom sessions, deeper analysis and more reflection is available. Secondly, faculty are aware that most students have a level of
technological literacy more advanced than their own. One participant noted that, one day, faculty accepting teaching positions at KTH will have studied in online and blended environments. Once that occurs, training courses such as this will no longer be required.

We cannot assess the impact of the course on actual teaching practice or course design with the current data set. Future research activity will include interviews with all participants to request information about the longer term effects of this course.

REFERENCES


BIOGRAPHICAL INFORMATION

Martha Cleveland-Innes, Ph. D., is professor and chair in the Center for Distance Education at Athabasca University in Alberta, Canada. Her current research interests are in the areas of leadership in open and distance higher education, online teaching and learning, and the effects of emotion on learning. She is currently Guest Professor of Technology-Enhanced Learning at KTH Royal Institute of Technology in Stockholm, Sweden.

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Sarah Gauvreau, M.Ed., is a Research Associate at Contact North | Contact Nord in Ontario, Canada. Her research interests are in the student experience in online and distance education environments. Sarah has been in the field of education for over the last 15 years in both the face-to-face environment (K to 12 and adult ESL) and in online training. Sarah has completed her Graduate Diploma of Instructional Design and Master’s degree in education, specializing in distance education.

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FOSTERING ENGINEERING THINKING WITH CURRICULUM INTERGRATED STEM GAME

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Siberian Federal University

Alexey Fedoseev, Yaroslav Fadeev
Moscow Polytechnic University

ABSTRACT

This paper shares the experience of implementation of STEM-based learning in the first year of engineering undergraduate programs for Metallurgy Engineering, Heat Engineering and Welding Engineering. STEM-based gaming competition “Engineering Cluster” is implemented under the scope of networking collaboration between Siberian Federal University and Moscow Polytechnic University in the first semester of 2016-17. The paper substantiates role and importance of STEM gaming activities at the stage of adaptation to learning process in university. Major issues concerning partial gamification of learning content are described. The results of “Engineering Cluster” competition showed that significant point is made in students’ abilities for self-study and solving interdisciplinary problems. Moreover, the game put attention to practical importance of natural sciences for understanding engineering problems. Overall, the proposed learning model could be a ground for change of mindset of both faculty and students on how traditional disciplines can be taught and learned.

KEYWORDS

STEM, Gamification, Introduction to Engineering, Engineering Thinking, Standards 3, 4, 7

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 designing real engineering products (Crawley et al., 2007). The CDIO approach could be adopted by the means of basal revision of traditional understanding of “education” turning then to active and project-based learning as a systemic basis for curriculum design.

At the stage of designing the CDIO-based curriculum, one will inevitably encounter a challenge of overcoming the traditional, historically accepted paradigms of learning and
common attitudes of students and teachers concerning education. The most probable systemic conflict emerges at the point of rethinking natural sciences – math, physics and chemistry. These disciplines dwell at the very fount of any technical education, being the stem for every engineering programme. However, due to complexity and ever decreasing formalizability of engineering problems, the conceptual knowledge of natural sciences alone is no more sufficient for modern engineer (Kamp, 2016). Thus, in most cases, the traditional theoretical mode of math, physics and chemistry 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 (Standard 8). Gaming activities are the form of active learning methods, based on principle that students acquire experiential knowledge through acting simulated gaming patterns. Games are best known for high learning efficiency caused by participants’ emotional immersion while reaching game goals and perceiving situations of success (Hamari et al., 2014). Implementation of gaming principles in non-gaming area, referred as gamification (Herger, 2014) became widespread phenomena in marketing, management, education etc.

The concept of STEM (Science, Technology, Engineering, Math) was created to answer both needs: to improve education quality in natural sciences and develop modern methodologic apparatus for these disciplines, as well as bring engineering context in learning process (Gonzalez & Kuenzi, 2012). Including both conceptual basics of natural sciences and modern gaming methods, STEM technologies can bridge the gap between theory and practice at earlier stages of engineering curricula. Despite the criticism of gamification phenomena (Fuchs et al., 2014), implementation of STEM games in learning process can be viewed as a stage of students’ acquaintance with problems of engineering professions at the beginning of their studies in university (Standard 4). The engineering context of STEM games put attention to significance and demand for integrative application of natural sciences to solve engineering problems.

Due to diversity of application area, gamification phenomenon focuses mainly on using IT. Considering both technologic potential and gradual digital gaming principles development, computer games, existing for a few decades, became one of the most influential media industries today. As long as IT, media and computer games remain significant part of youth culture, they can be successfully adopted to learning, increasing overall interest and motivation of students as well as learning efficiency. This phenomenon relates to the specific way of information perception by today’s young people, and was described in numerous studies.

In general, digitalization of content allows students to bring learning to more comfortable environment than a classroom – to their own devices. In the framework of basic disciplines of the first year of undergraduate programme, bringing content to youth-native digital environment using gaming context could facilitate students’ interest and change the mindset of studying natural sciences.

**“ENGINEERING CLUSTER” – A STEM GAME CONCEPT**

Aiming to change the learning process by gamification of content and digitalization of environment, Moscow Polytechnic University developed a STEM game “Engineering Cluster”
for 1st and 2nd year students. The game represents an online market simulator, where student teams become competitive companies developing high-tech engineering products. From educational point of view, “Engineering Cluster” utilize the content of physics, chemistry and math at the level of the first year undergraduate programme, bringing atop of that engineering and economical contexts implemented through project-based approach. The game plot suggests that students’ companies must compete at the product market by means of developed products quality and business strategy.

STEM game “Engineering Cluster” can be described through the following key features:

- **User-friendly interface**
  - The game developed as a website with simple and modern graphical structure, where main elements are supported with commentaries and guides. Training missions are available for faster acquaintance with game mechanics.
- **Mobility and self-organization**
  - The website is available 24/7 using any digital device with internet connection and browser, giving students a feeling of personalization and an opportunity for flexible planning.
- **Real-life products**
  - All products in the game are represented by calculation models of real-life products of engineering, adopted for the first-year engineering undergraduate programme level.
- **Learning content integration**
  - Each game product represents a problem in natural science discipline – physics, chemistry, or math.
- **Diversity and difficulty**
  - Game products are interdependent and ranged by difficulty: high-level products include several correlated low-level products. Every product has a multitude of potentially correct solutions.
- **Interdisciplinary approach**
  - High-level product development means parallel solving of different problems from different areas 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, which represents iterative process of planning-designing-simulating-production for each product.
- **Market economy**
  - Each team has its own economic potential influenced by quality and level of developed products. The teams undertake business transactions with each other at the game market.
- **Teamwork**
  - Considering multitude of game sub-processes, the key to successful play is to become a sustainable team with effective role management.
- **Responsibility**
  - Teams maintain their own game budget and make important decisions at every stage – from product requirements analysis to cooperation strategy.

The main principles of “Engineering Cluster” can be exemplified through general production cycle of one of the high-level products – Winged Rocket (Figure 1). In order to produce a Winged Rocket, the team must design its components: Rocket Engine and Accelerometer. The team will also need an appropriate Rocket Fuel in turn to produce the Engine.
Each product in the chain refers to a problem within a particular area of natural science:

- Rocket Fuel – heat of combustion calculation for selected fuel compound;
- Accelerometer – Hooke’s law application and statistical error analysis;
- Rocket Engine – calculation of heat balance for thermal system;
- Winged Rocket – flight trajectory analysis represented by saddle surface.

Figure 1. Winged Rocket production chain

Before undertaking a task, students must fulfil their knowledge in theory of these problems. In contrast with the traditional mode of study, students formulate the request for theoretical input at the point of encountering real-life practical problem during in-game product design. Thus, students can explicitly see the connection between natural science and engineering. Figure 2 shows a lifecycle of game product (see Appendix A for detailed stages explanation).

Figure 2. Game product lifecycle
STEM GAME CURRICULUM INTEGRATION: A COLLABORATIVE EXPERIENCE

“Engineering Cluster” offers salient educational potential to create an immersive practice in experiencing engineering context for first-year students. However, to maintain the salience, the complex and thorough planning are required starting from intercurricular integration of the game. This part shares the experience of collaboration between Moscow Polytechnic University (MPU) and Siberian Federal University (SibFU) for “Engineering Cluster” implementation in three CDIO-based undergraduate programs.

In compliance with CDIO Standard 5, “Engineering Cluster” was organized as a module in the Introduction to Engineering course in the 1st semester. The module workload was spread in 8 weeks including auditorium classes, special supporting events and self-study time. The timeline of the game is shown on Figure 3.

The module was preceded by a year of joint work of MPU and SibFU in developing the module structure: from staff training seminars and curricula design to results evaluation and awards ceremony. The key points of universities’ collaboration are explained in Appendix B.

STEM game “Engineering Cluster” as a part of educational process could be divided into three sub-processes:

1. Game Process
   - The overall module length is 8 weeks with the last week reserved for game conclusion, awards ceremony and feedback sessions
   - Main “Cluster Sessions” are organized on the regular basis as a part of Introduction to Engineering course (two classes per week)
   - Optional “Cluster Sessions” on students’ demand
   - Special “Troubleshooting Sessions” on a weekly basis
   - Overall classroom to self-study workload relation is approximately 40% to 60%

2. Game Support
   - Classroom support made by Introduction to Engineering teaching team
   - Coach-sessions of physics, chemistry and math teaching team
   - Senior-year student tutors support – game adaptation, strategy development, team building
   - “Natural Sciences Sessions” on students’ demand
• Website 24/7 technical support for error reports

3. Game Management

Administrators

• Website activity monitoring
• Product Order pool supply based on game plot and activity
• Regular meetings with teaching staff and tutors
• Learning Outcomes Evaluation
• Feedback collection

Teaching staff and Tutors

• Classroom teamwork monitoring, teams’ sustainability
• Game rules violation monitoring and ethics issues
• Low progress teams support
• Dispute solving

RESULTS AND DISCUSSION

Organization of STEM game module “Engineering Cluster” for CDIO-based undergraduate programs in the 1st semester of 2016 resulted in full-scale engagement of all the participants of educational process in effort to provide unique learning experience for students. Comprehensive statistics gathered from the game platform demonstrated positive dynamics in the number and quality of game products solved by students (Figure 4a). The chart shows the quality of every product introduced during the game and respective number of teams able to successfully produce it (see grey circles and orange dots aligned vertically). The increase of average quality of products could be explained through students’ adaptation both to the game mechanics and required mode of learning along the game progress. Overall game difficulty resulted in gradual decrease of successful players. However, it could be clearly seen that this mode of learning formed six strong and sustainable groups of students able to answer challenges. The results of feedback also showed students’ positive attitude towards practice-oriented learning, when solving engineering problems increased their overall interest in natural science (Figure 4b).

![Graph showing game statistics and feedback results](image)

Figure 4. Game statistics and feedback results

a) Student teams’ effectiveness evaluation
b) Students survey results
“Engineering Cluster” in numbers

- 120 students from 3 engineering programs formed 29 teams;
- Solved 15 product models of 17 available in the game, with average quality of 67%;
- 7 of 29 teams solved max number of models – 15;
- Total count of products produced – over 3000;
- More than 50% of students spent 2-4 hours to “Engineering Cluster” daily;
- Coach Sessions organized – over 30 hours.

Learning effectiveness

- High-level product accomplishment is only possible if students successfully solved every component’s problem;
- Average time spent in solving high-level product gradually decreased (from 14 days for the first available product, 10 days for second product, 7 days for 3rd and 4th) meaning the development of students’ ability to analyze complex product and solve interdisciplinary problems;
- Most students had successful experience in solving complex and ambiguous problems (support materials and technical guides provided no instruction or algorithm);
- Acting as an engineering company, students could immerse in the problems of engineering profession and use project approach to solve them;
- The game created a learning process beyond timetable and built long-term rapport between students and teachers, forming unique teaching-learning experience for both students and teachers.

Proposed approach to STEM game implementation in the learning process allowed to achieve significant results due to thorough planning and curriculum integration. Earlier experience of SibFU in STEM games learning were based on the students’ optional choice, lacking the motivation system and powerful support of the game process. The first launch resulted in disregarding the game by the students as non-obligatory activity, whereas most of them shifted their attention to another, “more important” courses. Teachers’ active support and commitment allowed to make “Engineering Cluster” the most rigorous and important learning event for students, dramatically increasing their learning motivation and overall interest to engineering profession.

Inferring from the results obtained by MPU and SibFU, the practicability of STEM games use in the first year of studies is defined by the following:

1. The need to acknowledge students with project activity at earliest stage (Syllabus 2.1).
2. Positive change of students’ personal attitude towards natural sciences (Syllabus 1.1).
3. In-game professional-oriented problems require integrated use of knowledge, methods and abilities of applying natural sciences (Standard 3).
4. Native for modern students form of education taking learning process beyond classroom
5. Using teamwork for solving in-game problems.
6. Personified learning with student’s responsibility for product quality.
7. Fostering students’ engineering vision of product as a complex system with lifecycle (Syllabus 2.3).
CONCLUSION

Implementation of STEM technologies combined with partial learning gamification for the first-year undergraduate students of SibFU demonstrated an opportunity to bring engineering context to the content of natural sciences. The “Engineering Cluster” game format allows to engage students with the problems of engineering profession, showing significance and necessity of integrated knowledge use for solving engineering problems. Intercurricular integration of the game and active staff support showed significant increase of learning effect. In general, the purpose of STEM games use could be formulated as creation of valuable and salient learning experience for young students, fostering engineering thinking and encouraging them for further active studying at university.

REFERENCES


BIOGRAPHICAL INFORMATION

**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 process.

**Aleksandr Arnautov** is a senior teacher of Metallurgy Engineering Department. He is currently a coordinator of international communications of CDIO Initiative at SibFU. His current research focuses on digital environment and information services implementation in curriculum design.

**Alexey Fedoseev** is a Director of Centre for Interactive Educational Technologies at Moscow Polytechnic University. He is an expert in engineering education and interactive learning practices including games, simulations and project-based learning. He is also a leader of STEM games project at MPU.

**Yaroslav Fadeev** is a postgraduate student at Moscow State University and STEM-games project lead developer. His current research is focused on the development of novel educational games, simulations and the assessment of their efficiency.

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APPENDIX A

Table A. In-game production stages

<table>
<thead>
<tr>
<th>Production Stage</th>
<th>Team activity</th>
<th>In-game situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Project Start</td>
<td>Start a new product with custom parameters or picking up Product Order from game pool</td>
<td>Winged Rocket production chain is available with technical guides for each product. The order is due in 72 hours. Producing a rocket with 75% quality will make a profit of 250 GC (Game Currency: millions of Russian Rubles were actually used)</td>
</tr>
<tr>
<td>2. Requirements Analysis</td>
<td>Studying requirements and limitations of each product in the chain, analysing products’ parameters cross-relations</td>
<td>The ‘operative’ rocket type defines the limitations in total mass and peak engine power. Land relief defines dynamic range of accelerometer. Engine thermal efficiency is influenced by the choice of fuel components</td>
</tr>
<tr>
<td>3. Designing</td>
<td>Calculation of product models. The challenge is in the lack of strategy given and product compatibility awareness</td>
<td>Considering the cross-related parameters, the best strategy is to solve all the models in parallel</td>
</tr>
<tr>
<td>4. Simulation</td>
<td>Game engine simulates product model using students’ parameters. Simulation log shows product’s resulting specifications. PDCA cycle allows students to make iterative corrections</td>
<td>Test rocket simulation (cost 20 GC) showed that rocket is operable. Comparing the results with product requirements revealed minor discrepancy, which could be corrected by increasing calculations accuracy.</td>
</tr>
<tr>
<td>5. Production</td>
<td>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</td>
<td>Time-saving decision is to buy Rocket Fuel on the market for 50 GC. Produced rocket quality is 85%, the production line costs 100 GC. Now the team can produce 85% grade operative rockets for cost price of 35 GC</td>
</tr>
<tr>
<td>6. Product Implementation</td>
<td>Two options for finished product: a) product is stored for market or further production b) product is utilized (deleted)</td>
<td>The profit for producing Winged Rocket is 80 GC. The team accomplished rocket production chain and can make custom rockets for other teams.</td>
</tr>
</tbody>
</table>
## APPENDIX B

### Table B. Roadmap of “Engineering Cluster” implementation

<table>
<thead>
<tr>
<th>Stage</th>
<th>SibFU</th>
<th>MPU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background for collaboration</td>
<td><strong>Facing the need for new educational practices, education quality improvement</strong></td>
<td><strong>Development of educational products for engineering programs</strong></td>
</tr>
<tr>
<td>Form of collaboration</td>
<td><strong>Networking agreement for long-term joint educational projects realization</strong></td>
<td></td>
</tr>
<tr>
<td>Defining the structure</td>
<td><strong>Learning module in the Introduction to Engineering course</strong></td>
<td><strong>“Engineering Cluster” format as an online STEM game</strong></td>
</tr>
<tr>
<td>1 year before launch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Defining the content</td>
<td><strong>Introduction to Engineering and Natural sciences syllabi for first-year undergraduates.</strong></td>
<td><strong>Developing context engineering tasks using requested content and workload</strong></td>
</tr>
<tr>
<td>1 year before launch</td>
<td><strong>Learning outcomes planning</strong></td>
<td></td>
</tr>
<tr>
<td>Planning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>During the year</td>
<td><strong>- Designing the curricula</strong></td>
<td><strong>Developing “Engineering Cluster” STEM game</strong></td>
</tr>
<tr>
<td></td>
<td><strong>- Documentation approval</strong></td>
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<tr>
<td></td>
<td><strong>- Resources planning</strong></td>
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<tr>
<td></td>
<td><strong>- Staff planning</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>- Student tutors planning</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>- Learning outcomes evaluation</strong></td>
<td></td>
</tr>
<tr>
<td>Staff training</td>
<td><strong>Training seminar for teaching staff and student tutors.</strong></td>
<td><strong>- Training seminar program</strong></td>
</tr>
<tr>
<td>1 month before launch</td>
<td><strong>Preliminary game testing</strong></td>
<td><strong>- Expert visit to SibFU seminar</strong></td>
</tr>
<tr>
<td>Game testing</td>
<td><strong>Test launch of the game played by teachers and tutors</strong></td>
<td><strong>- Feedback collection</strong></td>
</tr>
<tr>
<td>2 weeks before launch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Game launch</td>
<td><strong>- Launch event</strong></td>
<td><strong>Technical support and help desk</strong></td>
</tr>
<tr>
<td>1 week</td>
<td><strong>- Forming student teams and registration</strong></td>
<td></td>
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<tr>
<td></td>
<td><strong>- Introductory game session</strong></td>
<td></td>
</tr>
<tr>
<td>Module body</td>
<td><strong>- Regular classes and self-study</strong></td>
<td><strong>Technical support and help desk</strong></td>
</tr>
<tr>
<td>6 weeks</td>
<td><strong>- Teachers consultations</strong></td>
<td></td>
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<td></td>
<td><strong>- Troubleshooting sessions</strong></td>
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<td></td>
<td><strong>- Student tutors support</strong></td>
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<td></td>
<td><strong>- Activity monitor</strong></td>
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<td></td>
<td><strong>- Social and students mass media support</strong></td>
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<tr>
<td>Game conclusion</td>
<td><strong>- Evaluating the results</strong></td>
<td><strong>- Game data analysis</strong></td>
</tr>
<tr>
<td>1 week</td>
<td><strong>- Defining winner teams</strong></td>
<td><strong>- Awards ceremony for students</strong></td>
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<td></td>
<td><strong>- Awards ceremony support</strong></td>
<td><strong>- Expert visit to SibFU</strong></td>
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<td></td>
<td><strong>- Feedback collection</strong></td>
<td><strong>- Feedback collection</strong></td>
</tr>
<tr>
<td>Further collaboration</td>
<td><strong>Developing “Engineering Cluster” format based on feedback analysis.</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Expansion of collaboration range, further joint educational projects</strong></td>
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INTEGRATION OF CDIO SKILLS INTO PROJECT-BASED LEARNING IN HIGHER EDUCATION

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ABSTRACT

ICT is a demanding industrial domain where continuous development takes place. In Engineering Education, it is important that students gain competences relevant for the requirements of the working life. Learning environments providing opportunities for active participation and facilitating the intrinsic motivation of the students are important tools when reaching this goal. Furthermore, joint projects with external stakeholders enable universities to develop wider and closer cooperation with companies in order to help them with growth, digitalization and internationalization. Especially small and medium sized companies (SMEs) have lots of potential to grow but they need partners outside their own competence area to help them with product and service development. However, tight economic situation often limits the possibilities to buy these kinds of services from other companies and, thus, there is mutual interest in university-industry collaboration.

This case study presents how CDIO skills can be integrated into a learning environment based on projects assignments. This study focuses on “the FIRMA” that is a student-centric learning environment of ICT Education and Research Unit of Turku University of Applied Sciences (TUAS). The FIRMA is a student-driven project office that operates like a small company providing development projects to both university internal and external customers. Typical assignments include website designs, small-scale database applications, and end user training sessions. In addition, the FIRMA participates in several externally funded R&D projects, such as “SparkUp Gateway” and “Inside the Box”.

The CDIO Initiative has defined general goals for 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 in society (CDIO, 2010). A set of knowledge, skills and attitudes of future generation engineers is described in the CDIO Syllabus. Students in the FIRMA learning environment gain these skills by participating actively in many customer and R&D projects. Multicultural and multidisciplinary teams from different universities do innovative work together to meet the goals of the projects and develop a successful change process and increased competitiveness in customer pilots. This approach not only deepens the personal and professional skills and attributes but also interpersonal skills of teamwork and communication in authentic context. In addition, university-industry collaboration helps revealing new insights, helps the networking, and creates new and promising joint ventures with national and also international actors.
KEYWORDS
R&D learning environment, CDIO, ICT, Project-based learning, Standards: 3, 6, 7, 8

INTRODUCTION
In the ICT technical solutions and customer requirements change rapidly. Especially small companies might have lack of resources in ICT development if their core business is outside of the field. Universities of applied sciences among other higher education institutions are under increasing pressure to meet the rapidly changing needs of working life (Penttilä, Kairisto-Mertanen, Putkonen & Lehto 2013, 11). The curricula are often slow to respond the changing needs of the economy and fail to anticipate the careers of tomorrow. Therefore education should not aim at individual pieces of information that quickly become outdated or obsolete, but instead transprofessional qualifications (Kumpula 2014, 10). Students tend to work more systematically and accurately when the teaching of different professional skills alongside disciplinary knowledge is integrated in business context (Mejtoft 2016, 689). Also, the new funding models of the higher education has set up a pressure to improve operational efficiency, to strengthen the output-oriented approach and to increase the external funding. Developing and offering customer-orientated services to companies will deepen the academia-industry co-operation.

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 in society (CDIO, 2010). The ultimate goal is that the students gain competences relevant for the requirements of the working life and, thus, become able to aim at successful professional careers. (Rosilöf 2016, 425)

The FIRMA is a student-centric learning environment that works like a company. IT services and development projects are being offered for both TUAS internal customers as well as external customers, such as companies and foundations. Students use the knowledge gained in theory classes to solve practical challenges given by authentic customers. The main idea is that “everybody learns something, everybody benefits something”. Universities keep up the constantly changing edge of need in industry, students’ gain competences relevant for the requirements of the working life, SMEs get help and training to use technology more efficiently and ICT service providers do cooperation in order to make sure that they get more professional workforce later on.

In this paper, the focus is set to present a case study on integration of CDIO skills into project-based learning in higher education. First the methodologies used in the FIRMA are introduced. Thereafter the activities and the roles of the FIRMA are described and externally funded R&D projects are presented. Finally, the experiences on the past and current activities are discussed, and future development thoughts presented.

CDIO AND INNOVATION PEDAGOGY
One pedagogic goals of the applied universities in Finland is learning to learn. Students ought to be capable of collaborative learning as well as knowledge sharing in teams. They
Pedagogical objectives are met by using CDIO methods and innovation pedagogy in the FIRMA learning environment.

Innovation pedagogy is a learning approach that activates students to take an active and responsible role in their own learning. Innovation pedagogy emphasizes interactive dialogue between the educational institution and students as well as the surrounding working life and society. The methods used and the interaction between teachers and students establishes the basis for learning and thus enables the development of innovation competencies. Chosen methods and working with companies facilitate intuitive and unexpected learning during the learning process and transmission of tacit knowledge. The format of intuitive and tacit learning occur in the learning situation and it can be for example experiences on cultural differences or on working with customers (Penttilä et al. 2013, 17-18). Teams in the R&D projects customer pilots consist of variety of multicultural and multidisciplinary teams. Customer pilots are in most cases heterogeneous since the industry, size or background of the company is not restricted beforehand. Thus, intuitive and tacit learning varies case by case and the results as well as the learning outcomes depend on the co-operation between team members and co-operation between the team and the customer.

The CDIO Initiative has defined general goals to engineering education. However, using the CDIO principles should have influence not only in learning outcomes but also in RDI activities (Luimula, Suominen, Roslöf, Pieskä & Lehtiniemi 2016, 219). The 12 CDIO Standards (CDIO Standards v2.0, 2010) describe the features of CDIO programs. Integrating externally funded R&D projects and deep co-operation with working life via customer projects meets the standard 3. “Integrated Curriculum” objectives as learning experiences of the students lead to the acquisition of personal and interpersonal skills as well as product, process and system building skills. The standard 6, “Engineering workspaces”, emphasizes the importance of physical learning environment and hands-on learning. The FIRMA has own dedicated facilities at the campus where the students are able to work within teams during the customer projects. The FIRMA office is refurnished with workstations for the FIRMA “employees”, a negotiation corner and a small kitchen. The physical office provides opportunities for social learning and networking with other students. The standard 7, “Integrated learning experience”, focuses on acquisition of disciplinary knowledge, as well as personal and interpersonal skills, and product, process, and system building skills. Implementing authentic customer pilots will naturally lead to a result where the learning of disciplinary knowledge is simultaneously. The standard 8, “Active learning”, engages students directly in thinking and problem solving activities. The FIRMA is a company-like learning environment that calls for students to take an active role in their own learning. Hands-on project-based learning is a learning method of the environment. While working in customer pilots, students gain not only relevant technical competencies, but also social and problem-based learning skills.

A set of knowledge, skills and attitudes that alumni, industry and academia desire in a future generation of young engineers are being summarized in the CDIO Syllabus. The first-level set of knowledge, skills and attitudes are divided in four divisions: 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. First division include knowledge of underlying mathematics and science, core fundamental knowledge of engineering and advanced engineering fundamental knowledge, methods and tools. Second division consists analytical reasoning and problem solving, experimentation, investigation and knowledge discovery, system thinking, attitudes and learning, ethics, equity and other responsibilities.
Third division consists teamwork, communication and communication in foreign languages. Forth division include external, societal and environmental context as well as enterprise and business context, conceiving, designing, implementing and operating. (Crawley, Malmqvist, Lucas & Brodeur 2011).

THE FIRMA IN ACTION

The FIRMA is a student-driven learning environment that operates like a company providing development projects to both university internal and external customers. Most of customers are small or medium-sized companies. Typical assignments include website designs, small-scale database applications, and end user training sessions. (Rosilöf 2016, 425). Operation consists of four different units: externally funded projects, customer projects, sysadmin and help desk. The FIRMA participates actively in several externally funded R&D projects of TUAS. Sysadmin unit is responsible for the FIRMA network, software and hardware. Help desk is divided in two: external helpdesk provides services for external customers and internal helpdesk is part of TUAS helpdesk providing services for students and personnel of TUAS. The units of the FIRMA are presented in Figure 1. This paper focuses on externally funded R&D projects and customer projects of the FIRMA.

Figure 1. The FIRMA’s fields of operation.

The FIRMA was conducted in 2015 when the former project learning environments of TUAS ICT unit were united. Earlier, there were four different learning environments: “Education the Hot Potato SparkUp Gateway Inside the Box TRY OUT! Stages and Workshops for Growth Web development Gaming Testing Consulting Graphics Responsible for network, software and hardware Citizen Helpdesk TUAS Helpdesk
Support Centre Finland”, “Network Support Centre Finland”, “ICT-portti” and “Citizen’s Helpdesk”. The ultimate goal of combining the learning environments of TUAS ICT unit was to increase the performance of learning environment, standardize processes and expand the operation. The best practices of each learning environment was put in practice in the FIRMA. When developing the learning environment of higher education, one should keep in mind that the learning environment is not trying to compete with regional IT companies. For example in most customer cases, the schedule of the project is much longer than it would be when ordered from an IT company. Students always have time to learn during the projects since students are not professionals, they are still learning.

The FIRMA has an internal organization that consists of students. The student CEO is responsible for general administration, staffing and selling activities. In addition, the customer of the FIRMA is divided web development, game technology, marketing and communications, technical support and Helpdesk. One student project manager is responsible for each operation. The student project manager coordinates the assignments and is a contact person with the customers. The other students will join one or two of the operations based on their interest and competencies. The roles of the FIRMA operation is presented in Figure 2.

![Figure 2. The roles of the FIRMA.](image)

The students apply to the FIRMA either by joining ICT Services and Projects –course or by applying to a work placement in learning environment. The introductory course is for 15 ECTS credits, which includes a Microsoft Technology Associate exam, 5 participations in regional company presentations and project work done in the FIRMA. When applying to the work placement in the learning environment, students apply via light-weight recruitment process in the same way as they would apply to any small company position (Roslöf 2016, 427). Work done in the FIRMA 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. In addition, it is possible to complete tailored advanced professional studies in the FIRMA as well.

Once the applicant is accepted to work in the FIRMA the student can participate either on one project or continue to work in several projects and tasks throughout the studies. The customer requests and the projects are implemented using predefined processes. The customers are provided an offer including an initial version of the project plan as well as the cost offer. Most of the projects have a price tag, which means that customers pay to TUAS an agreed fee once the project has been successfully delivered. The income of the customer projects is used to cover some of the staff expenses as well as software and hardware updates of the learning environment. Most of the students get credits for working in project office. However, some of the most senior students (for example the student CEO) may get a limited number of hours per week salary in a student assistant role. (Roslöf 2016, 427)

TUAS staff provide guidance and mentor the students when needed, helps with the negotiations with customers and make sure that the learning goals are met during the projects. Currently there are three roles: staff project manager, responsible teacher and technical consultant. A staff project manager has the overall responsibility of the FIRMA 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 an assessments for the students. Technical consultants mentor the students in difficult engineering tasks that students are not able to solve by themselves. (Roslöf 2016, 429)
EXTERNALLY FUNDED R&D PROJECTS

Project-based learning approach not only deepens the technical competences but also leads to innovative co-creation with product and service development. In addition, university-industry collaboration helps revealing new insights, and help the networking and creates new and promising joint ventures with national and also international actors. Currently the FIRMA participates in five different projects: “SparkUp Gateway”, “Inside the Box”, “Hot Potato”, “TRY OUT!” and “Stages and Workshops for Growth”.

The main aim of the “SparkUp Gateway” project (2015-2017) is to enhance the competitiveness, growth and internationalization of the SMEs in Southwest Finland, and to strengthen and diversify the business services of the Turku region and the business development environment SparkUp, by taking advantage of the potential in higher education student collaboration. The goals will be met by 1. Executing multidisciplinary student projects to entrepreneurs and SMEs, 2. Productising the multidisciplinary competences of the higher education students in selected themes, 3. Developing the processes of student collaborations within the higher education institutions, 4. Producing new forms of student collaboration that meet the needs of the industry and 5. Establishing a unified path of student oriented entrepreneurship, from student driven projects to business development services, thus contributing to the promotion of student oriented entrepreneurship. The project is done in co-operation with Turku University of Applied Sciences, University of Turku, Turku Science Park Ltd. and Humak University of Applied Sciences. The project is funded by European Regional Development Fund. The Firma students have been active part of this project by participating in several customer pilot projects with other students of TUAS as well as with students from other universities. Working in international and multidisciplinary projects strengthens especially competencies in the area of cooperation and language skills.

“Inside the Box” project (2016-2018) goes right into the core of business, inside the company and seeks and creates digital insight, or inspiration that fits to the company’s situation. With this case-sensitive insight the company is able to implement a successful and effective digital leap, a development project and a change process. The ground for these actions is the skilled and experienced employees, that is, the business and work. The suggested development ideas contain new arrangements of work practices, new ways to work and (self-)manage work. These digitalization ideas and the development approach help companies to develop in a viable way especially the knowledge work. The results, new methods to engage digitalization leap projects, help also to improve work satisfaction and work satisfaction on employee level. The result of the project is new digitalization leap services that are tested and created with 40 customer pilots. The results of these pilot projects will also be presented to 160 SMEs in four seminar during the project. The project is done in co-operation with Turku University of Applied Sciences and University of Turku and it is funded by partner universities, companies and European Social Fund. Students in the FIRMA work with these customer projects, help organising the event, design and implement graphical ads and brochures for the project. Also, by joining the projects they gain deeper understanding of the work processes in the companies, which brings ideas how to do work more efficiently or how digital solutions might help companies to enhance their workflows or services. Working closely with customers’ give students’ even better understanding of the role of IT in companies outside of IT.

“Hot Potato” project (2017-2018) creates development services with a lever to meet the unique needs of SMEs in such a way the content fits to the adaptability capability of the SME. The levers are digitalization (including knowledge work, work flow), gamification
(including learning, training, and user satisfaction), and knowledge management (including management methods and objects in relation to productivity and well-being at work). The purpose of these rapid experiments is to inspire and motivate the staff and management at target companies to persevering development practice using collaborative experiment-oriented culture. The briefcase is the concrete product that enables the efficient dissemination of the lever-based tool for increasing productivity and work-being at work. The briefcase is used by the SMEs to evaluate and develop their performance and manage the change process. During the Hot Potato project, there will be done 50 customer pilots in co-operation with Turku University of Applied Sciences, University of Turku and nationally companies in Finland. The project is funded by partner universities, companies and European Social Fund. Students in the FIRMA will actively participate in the customer pilots as well as other tasks of the project, such as organizing three events for 200 companies. In the Figure 3 students of the FIRMA are getting ready to meet a customer.

![Image](FIRMA.jpg)

**Figure 4. The FIRMA students.**

TRY OUT! -project builds an innovation platform for circular economy and cleantech. The platform will be created based on experimentations and co-creation and it provides possibilities for new kinds of business models, cross sectoral cooperation and experimentations in circular economy and cleantech. The most vibrant models will be used and proceed into markets. Project promotes innovation activities and entrepreneurship in the fields of circular economy and cleantech. The innovation platform provides opportunies for participating companies to develop their products and services through pilot projects supported by experts, user communities and a multidisciplinary company networks. The platform will cover entire development cycle from an idea through piloting to market ready product. The innovation platform enables sharing of new insights, methods and innovations among participating companies, researchers and institutions. Therefore the project is set to promote attitude that endorses open-minded experimentations and fail fast and learn approach. TRY OUT! –project is done in co-operation with Turku University of Applied Sciences, University of Turku, University of Helsinki and Demos Helsinki. The project is funded by partners and European Regional Development Fund. The FIRMA students join this project by doing a requirement analysis for digital platform that enables companies and other users to share their surplus materials in order to find another company that could reuse it in their products or operations. In addition, the FIRMA students develop digital pilots for companies in the field of circular economy.

“Stages and Workshops for Growth” project (2016-2018) is done in co-operation with Turku University of Applied Sciences, City of Tampere, Tampere University of Applied Sciences, Helsinki Metropolia University of Applied Sciences, University of Turku, and Turku Science
Park Ltd. The aim of the project is to create and test a new kind of an approach for activating companies, students as well as experienced and skilled job seekers. Motivated and energized workgroups are established to solve identified growth challenges of local business. As a result of the project, work opportunities will be created for those looking for employment. TUAS organizes innovation workshops in co-operation with regional companies based on the needs of the company. The project is funded by partners and European Regional Development Fund. Students from TUAS will actively participate in the workshops. The FIRMA students gain relevant competences, more knowledge of the working life and connections while participating in workshops.

DISCUSSION & CONCLUSIONS

In this paper, integration of CDIO skills into project-based learning in higher education has been described and discussed. The student-driven ICT project office the FIRMA has been operating in its current form for two years now and the experiences are promising. It seems that the engagement of the students will enhance their learning, motivation and future career prospects. Especially combining larger amount of externally funded R&D projects into learning environment activities has expanded the academia-industry co-operation. In addition, the co-operation with other faculties of TUAS and other universities has strengthened.

The ultimate goal of combining the learning environments of TUAS ICT unit was to increase the performance of learning environment, standardize processes and expand the operation. Externally funded R&D project where not part of the former learning environments except in ICT-portti, which was able to implement one externally funded project at a time. Currently there are five different externally funded R&D projects going on at the same time as well as the customer projects of the FIRMA.

The difference between regular customer projects of the FIRMA and customer pilots of the externally funded projects (SparkUp Gateway, Inside the Box etc.) is that in most of the cases customer pilots are wider, multidisciplinary and done in closer co-operation with TUAS staff and other universities. In the FIRMA customer projects, a company might order for example a web site or Microsoft Excel training. The FIRMA students implement the project as agreed and then the project is ready. In customer pilots of externally funded projects, the scope of the project is typically wider. For example the idea of project might be developing and implementing suitable solutions to increase the digitalization of the company. In order to implement these kinds of customer pilots, deep understanding of the company goals, needs, processes, services, products and customers have to be met in the beginning of the project. This is done in co-operation with TUAS staff. Students that work in the FIRMA for a long period of time during their studies, work in customer projects of the FIRMA as well as customer pilots of externally funded projects. Innovation pedagogy methods and CDIO standards are relatively easy to adapt in externally funded R&D projects and especially in high-demanding customer pilots within the R&D project. According to standard 7. “Integrated Learning Experiences” the faculty is able to be more effective by helping students apply disciplinary knowledge to engineering practice and better prepare them to meet the requirements of the engineering profession. High-demanding customer pilots of externally funded R&D projects are excellent environment to provide integrated learning experiences to students.

The feedback from the students of the FIRMA is positive. According to the feedback, in the field of personal and professional skills, a deeper understanding of their own set of skills has
strengthened and the analytical reasoning and problem solving is more goal-orientated. In addition, the subfield of IT that a student wants to focus on in the future is crystallized. The outcomes of the projects motivate students in their studies once they understand better the connection between theory and practice. In the field of interpersonal skills and especially teamwork and communication has developed during the projects. Communication skills with customers as well as with other team members are in a significant role of the project. That is, industry want the future workforce to be not only technically capable, but also future generation of engineers should have social skills, passion to constantly learn more and capability to work in multidisciplinary and international teams. Combining these different sets of skills into environmental context will give results of future engineers that will meet the requirements of working life. In addition, students feel professionally more confident which supports the transmission to working life after graduation.

Naturally, there are also development ideas to consider in order to improve the activities of the learning environment. Currently students join the FIRMA either by enrolling to ICT Services and Projects course or by applying to work placement in the FIRMA. Most of the students that work in the FIRMA are in first or second year at their studies. The group of students that are in advanced stage of their studies is a lot smaller. This leads to the fact that the senior student group is not big enough to share their knowledge with all the junior students working in the FIRMA. In the future, the goal is to expand also the senior team so the knowledge sharing, social learning and interaction between junior and senior students is more active and fruitful.

Currently, feedback from the students is collected during a development day organized biannually. In order to evaluate the FIRMA’s actions in more depth, quality metrics should be carefully planned. For now, the feedback from the students as well as customers have been mostly positive. Many of the students that have been active in the FIRMA have been recruited to the local IT companies either already during their studies or in couple of months after their graduation. However, currently there is no detailed recruitment statistics available.

REFERENCES


BIOGRAPHICAL INFORMATION

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STUDENTS’ ROLE IN DESIGN-IMPLEMENT EXPERIENCES – CASE: HEALTH INFORMATICS PROJECT

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ABSTRACT

Health Informatics has been one of the focus areas of Information Technology education in Turku University of Applied Sciences (TUAS) since 2009. Since the beginning of Health Informatics education in TUAS we have been implementing CDIO-based procedures and standards such as active learning and design-build experiences. Our education is strongly connected with the industry and many research and development activities have been carried out with the industry and our eHealth Technologies Research group. All our RDI activities are strongly connected with the degree programmes and learning is embedded into the RDI projects too. Our students learn, work and earn credits in these real-life design-implemented experiences. One recent example of such a project is “Tools for information and language technology for the utilisation of health information for patients and professionals” RDI project (TAILOR in brief) funded by Tekes (the Finnish Funding Agency for Innovation). In this project our eHealth Technologies Research Group’s Lab facilities and engineering students work together with healthcare professionals. Other research partner in this project is University of Turku. In addition, there are number of industry partners involved such as Lingsoft, Fujitsu, BCB Medical and Hospital District of South-West Finland. In this project our part is a demo version of a user interface for creating and using tailored patient instructions and medical data. Our engineering students have many different responsibilities in this project. They are working on the user interfaces, use cases, documentation, testing and many other tasks. The project is operated using Scrum methodology.

The students participating the project were interviewed and their experiences on desing-implement projects were studied. All interviewed students valued highly the experience on working in a real-life project. They recognized the important role of different stakeholders. They underlined the role of lecturers in supporting the project implementation. Furthermore, they identified the role of projects in understanding the content of the lectures. Finally, they all wished for more project activities.

KEYWORDS

Health Informatics, TAILOR project, Engineering education, Standards: 5, 6, 7, 8
INTRODUCTION

Turku University of Applied Sciences has been a CDIO collaborator since 2007. One of the very first programmes that started implementing CDIO approach was the Degree Programme in Information Technology. Since 2007 many elements of CDIO approach has been introduced into the degree programmes (Kontio, 2016). From the beginning the CDIO features such as design-implement experiences, real-life workspaces, integrated learning experiences and active learning have had a strong role in our education. One typical way of connecting these elements into learning is to bring our RDI activities into learning. Our students learn, work and earn credits in these real-life design-implemented experiences. One recent example of such a project is “Tools for information and language technology for the utilization of health information for patients and professionals” RDI project (TAILOR in brief). The TAILOR project is a good example of hands-on learning where students are directly engaged in their own learning, and where students can learn from each other and interact with several groups. Learning in these project settings support several CDIO standards (Bennedsen et al. 2016).

Health Informatics is one of the focus areas in the Degree Programme in Information Technology in TUAS. This education started in 2009 after intensive planning together with the stakeholders (Kontio E et al. 2010). From the beginning this education has worked actively with the industry and other stakeholders. Majority of the studies in third and fourth year are embedded in real-life projects such as the TAILOR-project.

In this paper we will introduce the project in detail and describe the role of students in this design-build experience. The student experiences on working in a real-life project were studied and they are reported. In addition, we will report how we combined the emphasis on building products and implementing processes in real-world contexts giving students opportunities to make connections between the technical content they are learning and their professional and career interests.

TAILOR PROJECT

The TAILOR project started in autumn 2016 and is running until the end of year 2017. The project aims to create tools for tailoring patient documents, interactive patient instructions and medical information for patients and professionals. In addition, tools for analyzing health information related to heart illnesses and for tailoring information based on this are created during the project. Tools can be productized and developed for processing other health information as well.

The project's home base is in our eHealth Technologies Research Group’s Lab facilities where engineering and business information systems students work together with healthcare professionals. The University of Turku acts as other research partner in this project. In addition, there are number of industry partners involved such as Lingsoft Inc., Fujitsu, BCB Medical Ltd, and Hospital District of South-West Finland. The project is funded by Tekes (the Finnish Funding Agency for Innovation) and partner companies.

The result of the TAILOR project is an information system which support the patient's self-care. The information system tailors the information on patient's illness, treatments, treatment instructions and medicine from different sources into understandable form for the patient. The patient receives the information in electronic and/or printed form. The
information helps the patient understand his/her illness, commit to the treatment and participate in the related decision-making.

On the other hand, the project creates solutions which support professionals in producing and utilizing high-quality patient documents and instructions for implementing medical care. When producing text, the expert can use their own language and expressions. The language tools created within the project translate the texts automatically into the language used by the patient. They can also be enriched with photos, graphics, videos and other additional information. The aim is thus not simplifying plain language but using the language as a rich tool for understanding communication without compromising the information content. Professionals are also supported by the diversification of information retrieval and visualization of the desired information (e.g. medication, pain, disorientation), which is enabled by the tools based on the analysis.

We are planning, developing and testing a user interface using for the utilization of the background information created in the project. The background implementation, which is based on analyzing the tools, can be utilized in several commercial applications. The result is information applications which support the patient's self-care and with the help of which information on his/her illness, treatments, treatment instructions and medicine from different sources is tailored in a form that's understandable for the patient. The patient receives the information in electronic and/or printed form, and if they wish, saved on their personal health record account. Once the planned analysis engine of the TAILOR project is built, there are several other commercial possibilities to use the analysis features.

**STUDENT ROLES IN THE TAILOR PROJECT**

Working with real customers makes the project work concrete as the teams need to negotiate with clients about deadlines, content and the quality of work. This environment also teaches students to work with uncertainty. (Alarcon et al. 2013.) The TAILOR development project used user-centric methods together with possibilities in innovation pedagogy. The TAILOR project used three phases of CDIO approach: Conceive, Design and Implement.

A group of health informatics students started working on a TAILOR-project from September 2016. This work is being done within a Project management and processes in in healthcare environment course (15 ECTS) that students are taking part in. Course takes nearly entire academic year until end of April 2017. Student group’s task in TAILOR-project is to define requirements for the user interface of the developed patient instructions creation tool and conduct usability analysis and tests for it. In effect student group is responsible for requirements and usability engineering of the interface.

In Figure 1. is a weekly schedule for student group. Two hours on Thursday morning are reserved for lectures where students receive information relating to theoretical background required for completing their tasks. Tuesdays and Fridays (marked with red circles) are reserved for project work. Students are responsible for managing their projects by themselves but they are reporting project status weekly to course management.
Development work is being done using agile methods in two week sprints. Student team has chosen to use Trello for project management and communications. In Figure 2. can be seen project timetable that group has designed and are committed to. Timetable and project plan has been approved by course and TAILOR-project representatives.

During the autumn term student group has familiarized themselves with TAILOR-project and more importantly environment where patient instruction creation tools is going to be used as well as current process how instructions are given at the moment in university hospital. Based on that group has written user requirements for the instruction tool interface. Group is also having regular meetings with instruction tool development team. Key users from the Turku University Hospital has been detected and contacted to and user-centric design methods are being used by the group to ensure that developed tool will support current care processes and usability goals are reached.

Spring term 2017 will be used for defining and conducting usability tests for instruction creation tool. This will be done in close co-operation with aforementioned key users. Test results will be analyzed and transformed into design input by the student group to be implemented into the developed tool.

THE RESEARCH

This research had two parts. First, an open-ended online questionnaire was used to collect data on students experiences and feedback about the project activity. After the analysis of the questionnaire, semi-structured face-to-face interviews were conducted. Semi-structured interview method is designed to ascertain subjective responses from persons regarding a
particular situation or phenomenon they have experienced. It employs interview guide or schedule, and may be used when there is sufficient objective knowledge about an experience, but the subjective knowledge is lacking (Merton & Kendall, 1946; Morse & Field, 1995). Semi-structured interviews are used when the researcher knows enough about the topic to be able to identify the domain and the main components of the topics but is unable to anticipate all the possible answers (Morse & Field, 1995). The more extensive the investigator’s knowledge, the more precisely can the aspects to be covered in the interview be outlined in advance and the more significant questions may be posed (Kvale, 1996; Merton & Kendall, 1946).

In the first phase, the questionnaire was given to the students (n=10) working in the TAILOR project. The questionnaire had demographic questions and open-ended questions related to project working and learning experiences in design-build projects. The questionnaire had two main themes: 1) how project work supports learning and 2) how project work supports professional skills and professional growth. All students answered to this online questionnaire.

In the second phase, part of the students (n=6) were selected to the face-to-face interview. The interview questions were asked in the same way and in a systematic order from each of the students. However, the questions were semi-structured in that the interviewer was allowed freedom to diverge slightly from the script. The interviewer deepened and clarified the online questionnaire responses with the face-to-face interview.

The data was analyzed using content analysis. Content analysis is a research technique for systematically analysing written communication such as in this paper the questionnaire and interview data represents (Weber, 1990). It allows the researcher to analyze relatively unstructured data in view of the meanings, symbolic qualities, and expressive content (Krippendorff, 2012). In content analysis all answers are processed and interesting and relevant information is collected. Once all answers are processed major themes and categories are identified.

RESULTS

The purpose of this study was to identify the students experiences, challenges and feedback on working in real life design-build projects based on the questionnaire and students’ interviews. The demographic information of the students participating the study are following:

- Average number of credits 147 ECTS, min 119 and max 192
- Age of the students varied from 22 to 25
- Six students had high school degree, three students had vocational school degree and one students had both.
- All students had earlier experiences on project based learning.

One major theme of the research focused on how project work supports learning. The responses of the students show interesting observations starting from a comment saying that working in real-life projects is always the best way to learn. Students say that in practical projects they get a considerably better idea how things are made correctly. Students recognized that learning experiences in the projects support the topics learned in the lectures. They underline that the skills of the engineer are learned and deepened in the practice of the projects. They continue that learning of theory is more efficient through practice: *For example*
I have learned much more programming skills and more widely through the projects like on the courses of the programming. Another example shows the power of real-life projects too: A good example is documentation. When there is a purpose on the doing, it will be more sensible to make it; furthermore, the doing becomes purposeful and consistent.

The second major theme of the research focused on how project work supports professional skills and professional growth. Students identified several effect of project work on their professional skills and professional growth. First, students accredit the contacts with the working life stakeholders and experiences how things are done in real life. They also valued the communication needed with the stakeholders: these skills are priceless for today’s engineer, because most of the engineering is done in projects and teams. Besides communication skills they emphasized networking, presentations and management skills and methodicalness. Second, the project work gives students true experiences on working in various roles in a project. Students learn how projects are managed and what kind of procedures they have. Students stressed that successes in project work are very valuable, they improve students self-esteem and professional growth more than any lecture based courses. Finally, students underlined that their professional skills have improved – they not working with dummy exercises any more rather there are level of seriousness involved.

The research studies students experiences regarding the TAILOR project too. Overall the students were satisfied with the project activities and the actual project assignment. At the same time students said that working in the TAILOR project has been challenging but rewarding. The comments that students provided are consistent with the general statements presented above. Student underlined following issues:

- Working in the TAILOR project gave provided a good viewpoint to the work in a project
- I learned through the practice more and it was nice to work as a part of the group
- The TAILOR project has been a good way to try in practice topics that we have learned in the Health informatics lectures.
- Working in a TAILOR project was very motivating
- The project assignment was interesting and the industry stakeholders were very cooperative
- It would be nice to have projects like this even more.
- Working in this project made us to be considered important when we participated in the meetings of the project and were able to work with the professionals of different fields.

Out of the ten students only one provided a little unsatisfied comment: I have experienced the working frustrated. The biggest part of the time will go in scrum sprint meetings where the necessary matters are checked at a slow pace. The project work itself has not been too hard, but somehow the meetings take more time than to the working. I myself would want to have more practical work and a little less discussion.

At the end, students provided other comments regarding their studies and project based learning. Among the comments were views such as

- There should be more projects
- Projects should be interesting
- More projects already in beginning of the studies
- Projects are definitely important to our professional growth.
• The support of the lecturers and staff is important to the students in project based learning.

DISCUSSION

The aim of this paper was to describe the role of students in design-build experiences using one project as an example. The student experiences on working in a real-life project were studied and they were reported.

CDIO standard 5 rationalizes design-build experiences as follows for example:

• Iteration of design-implement experiences and increasing levels of design complexity reinforce students' understanding of the product, process, and system development process.
• Design-implement experiences also provide a solid foundation upon which to build deeper conceptual understanding of disciplinary skills.
• The emphasis on building products and implementing processes in real-world contexts gives students opportunities to make connections between the technical content they are learning and their professional and career interests.

In Health Informatics there are minimum two design-build experiences before students join our RDI-projects. TAILOR project was a good example of a project where the complexity increased and thus reinforces students understanding of the product development process. The results showed that project based learning deepens conceptual understanding of the professional skills and disciplinary skills. The results support the third rationale given above as well. Students clearly stated that they were able to make connections between the topics the learned in lectures and during the projects.

Our project based learning activities support the ideology of CDIO standard 7 too. With these projects we can help our students apply disciplinary knowledge to engineering practice and better prepare them to meet the demands of the engineering profession. Students responses confirm this obviously. Students recognized the important role of different stakeholders. In addition, they accredited the change to work with healthcare professionals. The one negative comment about project work shows that this students hasn't really understood the principles of project work yet.

Project work is also a form of active learning. Active learning helps to increase students' motivation to achieve program learning outcomes and form habits of lifelong learning. Certainly these elements were found in the students responses too. All interviewed students valued highly the experience on working in a real-life project.

The results of this research show that project based learning creates opportunities to students to make connections between the technical content they are learning and their professional and career interests.

All in all, the TAILOR project was a good example of design-build experiences and it carried out CDIO standards 5,6,7 and 8. In addition, this TAILOR project was also a good example of multiprofessional collaboration between engineering education and healthcare professionals. Furthermore, the TAILOR project agile development process plan-do-test-evaluate supported the project excellently.
The results of the present TAILOR project can be used in an information system which support the patient’s self-care and with the help of which information on his/her illness, treatments, treatment instructions and medicine from different sources is tailored in a form that’s understandable for the patient. However, the development work of the TAILOR solution is still needed dreadfully. In this paper the phases of development of the first TAILOR version were reported.

CONCLUSIONS

The results of this study show that design-build experiences provide valuable elements in engineering education. The key elements found in this research encourage programs to introduce project based learning into their programs. Using the words of the students we can conclude that

- Project work is a good way of learning
- Working with stakeholders is meaningful and valuable
- There should be more projects
- Projects support understanding of the lectures
- Working in real world design-build projects support professional skills.
REFERENCES


BIOGRAPHICAL INFORMATION

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USING BLOGS FOR AUTHENTIC ASSESSMENT OF PROJECT BASED MODULES

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ABSTRACT

Blogs used for education can capture snippets of an engineering project life and arrange information to show progression. Blogs teach students about writing techniques, online publishing and presentation, and proper Internet etiquette, which many students will use in future careers. More importantly, it helps to understand whether students have been able to appreciate a design framework such as CDIO as they progress through an iterative process.

Many project based modules in Singapore Polytechnic have been designed using the CDIO framework. These modules teach students to go through the CDIO process during the project cycle and appreciate the various stages. Facilitators have a requirement to monitor the design process at every stage and possibly at different iterations. Rubrics are designed to assess student teams on the process rather than the end product hence it is important for facilitators to have a snapshot of every stage of the project to assess and give feedback effectively. Using blogs, facilitators are able to carry out authentic assessments and align students to the design framework used as the project develops.

Blogs encourage community building in which both the bloggers and commenters exchange opinions and ideas. It also promotes open dialogue among student teams by encouraging them to comment on each other’s posts and give constructive feedback. It also serves as a platform to give students to express their content in their own way and hence boost creativity. Facilitators can also bring together a group of content experts for a given unit of study for students to network with on a blog. Blogs exhibit, organize, and protect student work as digital portfolios. As older entries are archived, developing skills and progress may be analyzed more conveniently. Furthermore, as students recognize their efforts will be publicly published, they are more motivated to produce better writing.

In this paper, the methodology of using blogs as part of project assessments in a module called Engineering and Design is shown. The paper also discusses a structure given to students to help scaffold the blog with posts that consist of appropriate content. The rubrics to assess these blogs will also be shown. Examples of blog entries showcasing the different CDIO stages and how student teams were able to steer their project design though continuous feedback and iterations for a successful completion will be presented.

KEYWORDS

Educational blogging, project-based learning, active and experiential learning, authentic assessment, Standards: 7, 11
INTRODUCTION

Engineering education has been evolving to nurture young engineers with a myriad of abilities and skills to satisfy the current industry needs. The industry require engineers to be equipped with communication skills that is not limited to fluency in solution presentations but be able to connect in diverse cultural and philosophical teams leading to complex communication and social skills as described by Samavedham KRL et al. Deeper and meaningful connections are made when student achievements are a product of a design process such as the CDIO framework. Dym, Clive L et al (2005) show that the purpose of engineering education is to graduate engineers who can design but also appreciates that design thinking is complex to teach. One of the effective ways to teach these processes is to immerse the student in real life problems and use design tools to craft a solution while stimulating higher thinking. The use of cognitive educational approaches and teaching while subjected to real-world contexts provides a need for authentic assessments that require students to apply their skills and knowledge to find solutions to real problems as shown in Custer, Rodney L., et al. (2000). Tenopir et al. (2010) show that communication skills, problem solving and interpersonal skills are the necessary soft skills in addition to technical skills for engineering students. It is important to note that communication skill is not limited to confident presentations but writing reports and also convey designs through detailed drawings and arrange information to engage an audience.

Assessment is a fundamental element of tertiary education as well as in industrial training and for most educators and students it is an important aspect of their coursework as detailed by Lamprianou and Athanasou (2009). Hence creating meaningful assessments that students find value is fundamentally a significant aspect for maintaining motivation levels in the classroom and maximizing learning. As more educational institutes move towards project and problem based pedagogies, authentic and sustainable forms of assessment that encourages self-directed learning focusses on assignments and tasks that have applicability to the world outside the classroom as described by Boud (2000). As a facilitator in project based modules, the role involves several and varied tasks to ensure an active learning environment. It is necessary to have forms of assessments that increases their efficiency and accountability through ways that promote quality and don’t hamper their other activities as mentioned by Fidler (1993). With affordable technological advancements, blended style of course delivery is becoming a norm for many programs offered by institutes of higher learning. Blended learning provides students with more control over their own study and an access to course material from any location. The self-control and self-regulated traits of blended learning often need to be regulated and monitored to achieve desired learning outcomes as shown in Zhu Y. et al (2016). Hence authentic assessments need to be carefully designed for project based modules that have elements of blended learning required to train the modern engineer.

Using educational blogs to assess students out of the classroom is one of methods to facilitate blended style of learning. Blogs can be used to document a processes and the milestones in a project cycle. There is a lack of literature that show studies on the effectiveness of students’ engagement and learning through blogging or other online
communication channels as described by Vu T.T. et al (2016). A framework developed through an investigation done by Jimoyiannis et al (2012) shows that students, through their blogging assignments achieved higher thinking and cognitive levels. Blogs used in a project based module, facilitate the process of giving feedback to students at different iterations of their project. Black P. et al (1998) describe that assessments that are designed to support a frequent feedback system helps in substantial learning gains. Blogs also help in practicing reflective writing due to its informal setting which is not a norm for engineering students. Burrows et al (2001) show evidence that students have better understanding of concepts and deepen their rationale of decisions made when they maintain a reflection journal about their project. In addition, it also improves their performance in the other assessments of the same module. The archive of such resources also helps facilitators design engaging activities as Bielefeldt et al (2010) tells us that reflective essays provide us a measurable means to understand evolution in student attitudes over time. Halada et al (2014) see the benefit of creating online journals for students during a course as through reflection on evidence and conclusions made it instigates more questions keeping the cycle of learning and discovery alive.

AN OVERVIEW OF THE MODULE

Engineering & Design is the third of four modules offered in a program called Engineering Academy in Singapore Polytechnic shown in Khan et al (2015). This program was designed to engage and nurture engineering students who are interested in designing and building real solutions. Each module consists of several multi-disciplinary activities which gives students the ability to understand how each discipline fits into more complex problems. The modules offered in this program are all project based and are held in specially designed studios. These studios aid in teamwork interactions, project building and conducting collaborative activity sessions. A workshop furnished with the state of the art equipment ranging from 3D printers, laser cutters, PCB milling machines and lathe machines, adjoins these studios for students to build and test their projects. The teams comprises of students from electrical and mechanical engineering schools who contribute with their wide-ranging expertise and skills. Teams often spend considerable time outside the module’s scheduled hours on their project and to facilitate this, they have their own lockers to access materials and are able to use the workshops and meeting rooms anytime during school hours.

In the module, Engineering & Design, students are given real life problems as project statements that they need to solve through their proposed solution. The problem statements given tend to encapsulate a multi –disciplinary issue which allows students to look at it from a different perspective. The solution needs to be mechanically robust to withstand the environment it is designed for and integrated with sensors and actuators. The solution has to incorporate a user centric design which requires user interviews and feedbacks at different stages of the project. The first half of the semester involves hands on activities conducted by facilitators from different disciplines to widen students’ perspective and gain understanding of related physical phenomenon. The last two semesters in 2015 and 2016, the theme was building systems that involve water. The hands on activities topics included water parameters sensing, filtration techniques, drag and buoyancy calculations, and hydroelectricity. The second half of the semester is dedicated to project building and students receive feedback at every milestone of their project cycle. This structure assists in establishing an iterative based project development. The module schedule is shown in Figure 1 with project milestones that need to be achieved.
As the module consists of several types of deliverables, assessments also vary in nature every week. The assessments are divided into individual and team components. Peer feedback plays an important role in identifying and awarding better scores for diligent team members. At the end of each hands on activity, a group assignment has to be submitted based on the group’s findings. Some activities are also supplemented with individual assignments that are meant to be challenging. As for the project, at every iteration, every team presents their updates in informal sharing sessions. Feedback and ideas from brainstorming are to be recorded so as to show how they helped to shape their project. At the end of the semester, each group would have delivered a functional prototype of their proposed solution and a blog that journals all hands on activities, project milestones and reflections.

A blog is maintained by each group from the beginning of the semester and it is updated almost every week. The main purpose of the blog is to monitor the different stages of the project cycle and observe the changes due to new research and comments from peers and faculty. Blogging guidelines and expectations are set at the first lesson with a structure that has deadlines for each post and the content it should have. As the blog is created for an audience, the quality of the content becomes a concern for the students and therefore it has been seen great efforts are taken to publish each post. To manage blogging and keep it effective as a tool for learning requires some effort from facilitators that they may not be used to in the other modules they teach.
using rubrics are also shown. Links to previous semesters’ blogs are also shared as guidelines.

As one of the main learning outcomes of this assignment is to foster collaboration, a closed group on Facebook with all students and facilitators is formed. This group helps facilitators to remind students of deadlines and share interesting reading material. Each team has to post a link of their new post on the group to share with others within the stipulated deadline. Facilitators comment on the blog post directly as well as copy the same content on the blog link shared by the team in the closed group. This helps to share the facilitator’s opinions with everyone in the class. One of the individual tasks for students is to comment on another team’s post which is assessed by a separate set of rubrics at the end of the semester. The closed group on Facebook helps facilitators to keep student engagement productive and non-static.

**Documenting a design process**

Modules that have been designed using the CDIO framework often have assessments that would like to ensure that students have been through each stage and more importantly, see the value of proceeding into a project using a design technique. Often the tangible part of the project cycle are highlighted and grades are reflected based on how successful the end product is. To appreciate a design process, each part of the process must be equally emphasized to students. Verbal feedback to students and written reports submitted to facilitators are usually the form of communication and assessment in the earlier stages of the projects. However, these methods lack exhibiting the entirety of the project cycle. Although all activities for such modules have been prepared to achieve all the stages of the CDIO framework, it is difficult to showcase them explicitly at a defined stage and how it aided in the development of the next one.

In Engineering and Design, the CDIO process is carried over several activities and project milestones. To help students Conceive ideas for their project, a few project statements are given to each group. This gives them a sense of autonomy in choosing their project. After conducting a thorough research about the different project statements given, the first blog post is written. This post describes each statement and the reasoning behind choosing the particular statement. The post also includes what are the state of the art solutions available for the problem at hand. It also details what is lacking in the available solutions and would like to address in their solution. Weekly hands-on activities’ reports and reflections on how the knowledge and skill acquired can be used in the project building are posted on the blog. The following project related posts start moving in to the Design stage named as the Specification and Concept report discussed in the next section. All blog posts needs to show detailed mechanical designs and electrical schematics. Facilitators use these posts to give each team technical feedback before they phase into the Implement stage. While building the prototype, each team would blog about their project progress and interesting problems that they faced and what solved it. The final post in the Operate stage, details the user experience of the solution and a video to demo how the solution would work to solve the problem assigned to them. Students at this stage feel proud of their accomplishment and the blog helps them to see the entire process they have been through and take back as a documented learning journey for future projects.
Improving communication skills

Blogging can be used to improve student writing skills especially that involves analysis and critique. Blog platforms allow students to learn to use various forms of digital multimedia that would convey the idea effectively. The layout of blog posts is suitable for concise reports hence it is important to learn to curate information that would best connect to your audience. Blogs also provide a way for students to clarify concepts learnt in class after their post is assessed by a facilitator. Blogs create spaces where students reflect on decisions made and feedback given through comments. Often many group members are unable to express ideas and concepts in a social setting and may be marked down for communication skills. Blogs help such students to voice out opinions as well as explain ideas in a non-intimidating setting.

In Singapore Polytechnic, engineering students are subjected to assessments that mostly consist of multiple choice questions and mathematical problem solving. Students often lack technical writing skills particularly that involves analysis. This causes friction for many groups in Engineering & Design to start their blog and often their first post is a landslide of information collected from the web with little effort to connect them and show purpose to the user of the research done. Facilitators’ feedback at this stage is very crucial to provide apt remarks about the writing as well as garner interest in students to write better in future posts. Examples of technical blogs is a good resource for students to learn from. It has been observed that every team were able develop clear arguments towards their final posts with strong reasoning and evidence. It encourages students to reflect on how the journaling affected their ideas and knowledge. When students revisit their concepts later in time, they realize the value of their own insights and how they have transformed with justifications.

Promoting collaboration and teamwork

Blogs provides an opportunity for fostering collaboration among group projects and to engage in meaningful discussion. When projects have a similar theme, often teams have the same plaguing problems that hinder progress. When one of the teams can solve this problem, this can help other teams to adopt the same solution and give credit to their peers in their blog. Students are able to learn from each other over the entire semester, especially when the facilitator aids in promoting certain posts and emphasizes what went well in conveying information effectively. Many teams make use of open source material such as Arduino code and 3D designs found on the Internet. Facilitators can use this situation to instill ethics in students to learn to acknowledge others’ efforts and include proper referencing in their posts.

Maintaining a group blog helps to bond teams which is unarguably one of the key elements for a successful group project. The team tends to show a sense of ownership over their ideas and this accountability is stronger as their thoughts are on a public stage. Teammates vet their post internally before it is published which helps them to agree on technical details and features of their design. This promotes and in a way compels group members to be aligned to their target design and deadlines. Students are allowed to choose their own platform for hosting their blog and are able to customize it with pictures and multimedia that best represents the team’s identity. The module requirement is to use a platform that can accept posts and allow public comments and doesn’t reward for elaborate features or design. However, as the semester progresses, students put in impressive efforts that promotes their project and user experience of their blog. Some of them promote their blog on open source technological sites to share their work which shows evidence that many students find value in engaging documentation of the team’s efforts.
**Project showcase**

In Engineering and Design, students spend many hours in school to work on their project. The blog helps to showcase their hard work to various stakeholders. Facilitators can closely observe progress and use as resources to share with other teaching members. It also helps management of the course to review the progress and quality of student work of a particular cohort. Using previous student blog posts as content for the next semester batch can really aid to motivate students to write their first post and manage expectations. The archive can also be used by faculty supervising final year projects that may have similar elements as the projects in the blogs especially at the beginning when students are conceiving their project scope. Many of the tangible projects are on display at the labs to motivate future students and impress visitors. Tagging these projects with a link with their blogs help to disseminate more information about work done by students in Singapore Polytechnic to various visitors.

A handful of projects in the module are done in collaboration with industry partners. The blog helps the company personnel to track the progress of projects and give their insights and suggestions for improvement at the right time of the project cycle. It also helps these personnel to update their management of project progress. Facilitators teaching this module send out links to fellow colleagues, industry experts and former students. This generates the visibility and readership of student’s work and the comments help each team to gather valuable insights. These comments help to gain perspective from potential users and related industry practitioners. Often key design or technical elements that have been missed out have been pinpointed through these comments. This helps students to learn how to deal with varied opinions and whether they are significant enough to pivot changes in their projects’ designs. Students also get to exhibit their projects in local engineering shows and Maker Faires and the blog helps them to exhibit with ease as the presentation content is substantial on their posts and videos.

**Blog rubrics**

As the blogging is part of the assessment, clear rubrics are shown to students at the beginning of the semester to set clear expectations as shown in Table 1. As the assessment of the blog leads to both individual and group scores, the posts related to each component are clearly highlighted to avoid confusion. The blog post rubrics allow the facilitator to grade the post based on whether the objective of the post was met, coherency and organization, creative arrangement of topic, proper citations and quality of writing and proof reading. The commenter on blog posts are assessed by separate rubrics as shown in Table 2.

As the lesson plan shown in an earlier section, the hands-on activities are at the beginning of the semester. For each activity, the post is written by a single author that receives the score. The group posts are at each project milestone with the following requirements:-

- **Project selection** - This post helps readers understand which project statement was chosen with reasoning and elaboration of the state of the art solutions available for the problem given. The team members are also introduced in this post with a brief description of their skills and expertise.
- **Specification report** - This post should include the main functions of the proposed solution. Rough sketches, a list of sensors, actuators and building materials should be shown to give form to the project.
• Concept report - This post should include the proposed user experience for the solution with detailed 3D sketches, complete wiring and block diagrams and project timeline.
• Technical report - This post updates readers about implementation progress of the project and any changes in the design with reasoning.
• Final report - This is the final post on the blog which helps readers to understand the need and the functions of the solution. There is also a video attachment that introduces the problem, solution, the design process and demo of the solution.

Table 1. Rubrics for a post on the blog

<table>
<thead>
<tr>
<th></th>
<th>Exceptional (20 points each)</th>
<th>Satisfactory (15 points each)</th>
<th>Limited (10 points each)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content of the blog post</td>
<td>The given topic fully discussed with valid proof based on experiences and research. Viewpoints and comprehensive reflections exhibits deep understanding.</td>
<td>The given topic was discussed with limited depth and proof. Moderate insights and reflections is exhibited.</td>
<td>The given topic was barely discussed with no proof or examples. Did not show any reflective thoughts.</td>
</tr>
<tr>
<td>Coherence and Organization</td>
<td>The blog post is coherent and well-organized integrating apt examples and analysis.</td>
<td>The blog post is somewhat difficult to follow with reasonable organization of content.</td>
<td>The blog post is not organized and displays no interest in organizing the content.</td>
</tr>
<tr>
<td>Creativity</td>
<td>Blog post was engaging and used several creative elements to effectively engage the reader such as multimedia, web links and pictures.</td>
<td>Blog post exhibited limited creativity using multimedia etc.</td>
<td>Blog post was uncreative with no elements of audience engagement.</td>
</tr>
<tr>
<td>Citations</td>
<td>All images, media and text created by others display appropriate copyright permissions and accurate citations.</td>
<td>Most images, media or text created by others display appropriate copyright permissions and accurate, properly formatted citations.</td>
<td>No images, media or text created by others display appropriate copyright permissions and do not include accurate, properly formatted citations.</td>
</tr>
<tr>
<td>Quality of writing and proofreading</td>
<td>Written responses contain numerous grammatical, spelling or punctuation errors. The style of writing does not facilitate effective communication.</td>
<td>Written responses are largely free of grammatical, spelling or punctuation errors. The style of writing generally facilitates communication.</td>
<td>Written responses are free of grammatical, spelling or punctuation errors. The style of writing facilitates communication.</td>
</tr>
</tbody>
</table>
Table 2. Rubrics for commenting on a post

<table>
<thead>
<tr>
<th>Comment's content and quality</th>
<th>Exceptional (20 points)</th>
<th>Satisfactory (15 points)</th>
<th>Limited (10 points)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The commenter shows there was clear understanding of the post and has given constructive feedback.</td>
<td>The commenter seems confused about the post and questions posed seemed slightly irrelevant.</td>
<td>The commenter made very little effort to give any feedback or pose any questions.</td>
</tr>
</tbody>
</table>

**Facilitator’s role**

A key observation in using blogs for achieving learning outcomes as with any assessment is the role of the facilitator. As the blog in Engineering & Design serves to replace technical reports and achieve greater exposure of the projects, facilitators need to be committed to their feedback and critiques. Prompting students at the right stage of the project cycle to post on their blog is essential in presenting the value of journaling their process. With experience, it is easy to pinpoint students that cut and paste their work onto the blog without any substantial reasoning. Facilitators need to intervene in these situations to suggest what is lacking in the content which leads to creating an engaging space outside of the classroom.

There are facilitators from four different disciplines namely, electronics, mechanical, chemical engineering and mathematics in Engineering and Design. Each of them would leave comments on their respective hands-on activity related posts. These comments may include words of encouragement for good work shown, correction of technical matter and challenge critical thinking with questions. For project related posts, all facilitators would pose their questions and recommendations. This allows facilitators to virtually interact with students meaningfully at their convenience.

**Examples**

In Semester 2 of 2015, there were 16 teams in the Engineering and Design module. A team named Imp-Bot were tasked to design a vehicle that was able to collect water samples from the swimming pool at two different depths. First, the team conceived to have a floating vehicle that would encompass two sampling containers that would be lowered down using a linkage system. Later, after a few calculations as well as new research done, they thought linkages would difficult to construct and it could be easily replaced with a simple spool system. Figure 2 show a snapshot of the initial design constraints. Figure 2 shows progress a weeks later with detailed features of the proposed design. The blog can be accessed at https://endteamsix.wordpress.com/
Another team who called themselves the Sea Monster, was asked to design an underwater vehicle capable of taking pictures. The team started off with a design that was meant to move around underwater and send pictures to a remote station on land. They quickly realized, the wireless communication methods available to them would not be able to transmit underwater and changed their design to add a tether to transmit data. Figure 3 shows the several iterations the project went through before it successfully was able to take pictures and send back to the user with ease. Sea Monster’s blog can be accessed at http://shyanjieteo.wixsite.com/group5end.
New Age Solutions team was formed in Semester 2 in 2016. This team was supported by Bosch as an industry partner. The project was conceived during a student community trip in Indonesia. The team found out that humidity levels in mushroom farms was an important parameter to control for better yield. The team first went through a learning journey at a local mushroom farm in Singapore. Using a sensor box given by Bosch, they were able to implement the project. The solution was able to send several parameters back to Singapore for analysis over a data network. The on board computer was able to analyze data over a period of time and was able to send an alert SMS to the Indonesian mushroom farmers to make necessary provisions to increase humidity levels or other prescribed form of actions. Figure 4 shows the project cycle of the team. The blog can be accessed at http://newagesolutions.wixsite.com/eagroup1.
DISCUSSIONS AND RESULTS

The facilitators teaching the module Engineering and Design used blogging as a form of documentation for two semesters. Each semester there are eight teams comprising of 6 students in each group. Each group needs to maintain a blog for the entire length of the semester. Prior to blogging, students had to hand in technical reports. These reports were marked with comments and returned to the group for review. The review helped them to write better for the next report and refer to designs when required as they were documented in detail. However, with reports it lacked a methodology to keep all stages of the project together for anyone to review at any time. Reports also lacked the component of deep reflection of the design process.

Although the module lacks traditional technical writing which is a one of the skills required in engineering students, blogging has helped in arranging ideas and designs to productive outcomes. Engineering students in Singapore Polytechnic are exposed to technical writing in communication, writing and engineering modules as well as for their thesis in the final year. Hence, blogging introduces an alternative avenue to communicate which is a current trend among many engineers adopt in the technopreneurial world. The content of the blog for the module...
is extensive in terms of technicality and reasoning for the design embraced. It has been observed that providing a proper scaffolding for the blog contents along with rubrics maintains expectations and quality of posts produced.

The project quality and learning outcomes have greatly benefitted through maintaining a record of the design stages. Each team was able to see their hard work evolve at every stage and lessons learnt were documented that helped them to not repeat them again at a later stage. This also helped the entire class benefit from each other’s solutions to problems faced and reduce time in debugging. It has helped facilitators review the entire process and assess the design process effectively resulting in constructive feedback for students. The projects produced were detailed, functional and addressed the critical needs of the users. In earlier semesters when blogging was not used, there was about thirty percent of projects that failed to reach the demo stage to show basic functions. Blogging has helped facilitators intervene at the right timing of the project stage and help each team steer the project deliverables that are achievable and within scope. This had led to all groups producing functional prototypes.

As the blogs took up a twenty percent of the total grade for the module, it was important to understand if students found value in this form assessment. Some qualitative feedback from students are shown below:

*Having to write a blog seems more interesting and I get to see the journey along the way. If I ever want to look back or show a project I worked on, I could just access it on the web instead of stressing to find reports that are somewhere in the computer memory.*

*The blog helped me to reflect on the decisions I made through the semester. When I go through my team’s blog, I can see how my decisions have matured from day one and the result is a functional vehicle due to all the feedback we received and actions made.*

*As I hope to participate in Maker Faire and engineering shows, it is often difficult to showcase my project and how I came up with the idea and what are the hurdles I went through to get to my final stage. The blog helped me to articulate the process and share solutions to common problems faced by many of my peers during the semester.*

**CONCLUSION**

This paper presented on how using a platform such as blogging that is familiar to our students can be used as a form of documentation for a project based module. This helps students, facilitators and external organizations create an environment that is an active learning space which promotes networking and collaboration. It is critical to set expectations using proper guidelines for the nature of each post on the blog to make it a meaningful assessment. Facilitators need to be active to monitor the progress of each group and give feedback when required as well as share applicable resources.
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BIOGRAPHICAL INFORMATION

Rubaina Khan, Rubaina Khan received her Master’s in Automation and Computer Control from Nanyang Technological University, Singapore in 2008 and currently a lecturer in School of Electrical and Electronic Engineering at Singapore Polytechnic, Singapore. Her research interests are in underwater robotics. She is also interested in experimental pedagogy techniques and in designing learning experiences that foster students’ creative capacities and also encourage students’ development as unique and self-directing learners.

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DEVELOPMENT OF THE LEARNING PROCESS IN A PROJECT-BASED LEARNING ENVIRONMENT

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ABSTRACT

“the FIRMA” is a project-based learning environment at Turku University of Applied Sciences (TUAS). The FIRMA offers students an opportunity to work and learn in real customer projects and also gain credits. The projects in the FIRMA are usually related to the ICT field. Typical project assignments include, for example, web development, database or game design tasks, digital marketing and Lego robot building camps for children. Customers are usually local small or medium-sized enterprises. For students, working in a real customer project is a meaningful alternative for learning compared to sitting in a class. For customers, the FIRMA offers a cost effective way of getting small IT-related projects done. In 2016, over 150 students worked in the FIRMA’s projects, earning approximately 1500 ECTS credits. In order to handle such amount of students and ensure their professional growth, we need to define a well-structured and easily applicable learning process. A well-defined learning process clarifies the assessment of the project work for such a number of students and enables the growth of the FIRMA in the future. This paper describes the FIRMA’s learning process. The learning process takes into account both CDIO and TUAS’ Innovation Pedagogy principles. The FIRMA provides an active learning environment that offers integrated learning opportunities covering all parts of the C-D-I-O core (Crawley et al., 2007). Innovation pedagogy is an approach for learning and teaching that enables students to learn working life skills and take responsibility for their professional growth (Penttilä et al., 2013).

KEYWORDS

Learning environment, learning process, assessment, CDIO Standards 3, 5, 6, 7, 8

INTRODUCTION

"the FIRMA" is a project-based learning environment in the Information and Communication Technology (ICT) unit of Turku University of Applied Sciences (TUAS) (Roslöf, 2016). The FIRMA was established in 2015 by combining multiple learning environments, such as "ICT-portti", Education Support Centre Finland (ESC Finland), Network Support Centre Finland (NESC Finland) and Citizen’s helpdesk. All these learning environments were operating at the ICT unit at TUAS but they had different areas of operation. ICT-portti was a joint project and learning environment of TUAS and Turku Science Park. ICT-portti aimed at improving the IT skills of local small and medium-sized enterprises as well as improving IT education in
general (Eura, 2007). ESC Finland was a company-like learning environment that was created in co-operation with Microsoft Finland. ESC Finland provided software support for Microsoft products for schools, educational institutes and non-profit organizations (Leivo & Granholm, 2012). Whereas ESC Finland concentrated on Microsoft products, NESC Finland concentrated on producing open source solutions for the Finnish public sector and local companies. Citizen’s Helpdesk provides local citizens with free computer support services, such as software repairs, software updates and removing computer viruses.

Figure 1 illustrates the FIRMA and its current operations in a nutshell. For example, the FIRMA participates in various externally funded projects and offers local companies small IT projects at a reasonable price. Furthermore, the FIRMA’s networks and computers are maintained by system administration run by students thus covering also the operate part of CDIO. Students also manage and run the Citizen’s Helpdesk.

The FIRMA has many similarities with other learning environments, such as Buro (“Buro”, n.d.) or Demola (“Demola”, n.d.). Buro or B302 is a media consulting agency at HAN University of Applied Sciences in the Netherlands (http://www.b302.nl/). Buro creates mainly multimedia projects for its customers. Buro has a lot of similarities compared to the FIRMA: in both students work on real customer projects. Buro has less students per year than the FIRMA, but all students get paid and are naturally treated more like employees than students. In the FIRMA only a few students get paid but all students get credits. The learning approach is however the same: Learning by doing. Buro has also started an office B507 in Minnesota State University in Mankato in USA (https://www.b507.us/) and B353 in Ireland will open in 2017.

Demola (http://www.demola.net/) is an innovation environment (or innovation platform) where students get the opportunity to work in teams to solve real-life cases with partner companies. Demola does not operate under any university as such, but students from the University of Tampere, Tampere University of Technology and Tampere University of Applied Sciences
can join Demola and get credits. Whereas Buro and the FIRMA are mainly targeted to ICT students, Demola welcomes students from various degree programs ("Demola", n.d.).

THE FIRMA OPERATION AND ADMINISTRATION

Even if the FIRMA is a learning environment and operates under TUAS, it is managed like a real company. That is, a student chief executive officer (CEO) leads the FIRMA, a student marketing manager is responsible for the FIRMA's marketing and graphical image, student project managers manage the projects and student system administrators maintain and develop the FIRMA's network and computers. Students are selected to those places based on their performance in the FIRMA projects and also based on an interview. Figure 2 depicts the FIRMA students having a project meeting.

![Figure 2. Project meeting in the FIRMA](image)

Also a few TUAS staff members look after the FIRMA operations. One teacher is responsible for the FIRMA’s project process and students getting their credits and grades. Another teacher acts as a key account manager (being responsible of the project contracts and initial negotiations with the customers). Currently also one project engineer is coordinating the funded projects together with the responsible teachers. In addition, it is possible to use other faculty members, both teachers and project staff, as expert mentors if the projects include challenging topics connected to their areas of expertise.
THE FIRMA STUDENTS

Majority of students active in the FIRMA are studying in the ICT-focused Bachelor of Engineering or Bachelor of Business Administration degree programs. Some students study only a few credits in the FIRMA whereas other students study a major part of their degree there. Basically students can complete their whole degree in the FIRMA, except the compulsory science studies (such as mathematics and physics). Students have two ways to enter the FIRMA: They can do internship in the FIRMA or they can attend a course called ICT Services and Projects that contains 7–10 credits of project work in the FIRMA. Figure 3 shows students working in the FIRMA premises at TUAS.

Students studying in the FIRMA usually start as project members in real projects where more experienced students mentor them. As soon as students’ skills and professional self-confidence grows, they start helping out the newer FIRMA students or they even become student project managers. It is also possible to apply for more responsible roles, such as student marketing manager, head of system administration or student CEO.

Since autumn 2016 it has also been possible to study the whole competence track in the FIRMA. The competence track means the studies students take on their third and fourth year (in other words, it is their major subject). For each student we set personal learning goals so that we ensure that students’ skills fulfill the overall learning goals of ICT engineer education. In practice this means ensuring that competence track students' projects are enough challenging and the projects require learning and mastering of wide range of skills.

In the academic year 2016–2017 the FIRMA competence track is in a pilot phase and therefore only four students are on the track. One concentrates on system administration and the other three concentrate on project work in development projects and project management. In the academic year 2017–2018 about 10 students will be selected to the FIRMA competence track based on an interview. We aim at increasing the number of competence track students in the future.
THE FIRMA PROJECT PROCESS

As mentioned, the FIRMA was established by combining multiple learning environments a few years ago. Best practices from all the learning environments were combined and became the FIRMA’s project process. However, the project process had a few shortcomings. First, students only got project credits and no grades (with the grade ‘passed’). Second, the quality process was heavy and as such not the most suitable for the FIRMA. Third, students were required to fill in a learning diary each month. Since students typically work in the FIRMA projects only a few hours a week they seldom had anything new to write in the learning diary. The same diary entry was usually copied and pasted to the next month’s diary, which did not support students’ professional growth. An improved learning process was developed in 2016. At first the project process was divided in two parts: quality process and learning process. The quality process defines how to maintain and improve the quality of the projects and the operations of the FIRMA (Määttä et al., 2016). The learning process defines how the students are able to demonstrate their competences and, accordingly, gain credits and grades. This paper describes the new learning process in more detail.

The New Learning Process

In the FIRMA, 27 hours of project learning/work equals one credit (according to the European Credit Transfer System definition). Students mark their hours in an hour tracking Excel and return the report monthly. The student CEO collects the hours three times a year for the teacher, who will then give the students credits and grades. Grades are formed based on students’ self and group assessment, project’s customer’s feedback and teacher’s assessment. The grading scale used in the assessment uses numerical grading from zero to five, where zero means fail and five means excellent. The assessed areas include the development of technical skills, following of the FIRMA’s practices and student’s work performance. The rubric can be found in Appendix 1.

The monthly learning diaries were replaced with learning objectives for each project. The project group determines these learning objectives in the first project meeting. The objectives can be the same for each group member, but they can also be different for different students. For example, a project manager’s learning objective can be to learn a new project process whereas a project member’s learning objective can be to learn a new programming language. After the project is finished, the project group evaluates how well the objectives were met. This helps students to take more responsibility for their own learning as they also have to actively evaluate and reflect their own progress.

When students enter the FIRMA, they are usually assigned to projects based on their own wishes. Some students want to develop their programming skills whereas other students are more interested in graphic design or digital marketing. The first project can be a very small and simple one and as soon as the student’s skills and self-confidence grows, the following projects will be more challenging. This way we enable and also ensure the professional growth of the students. Not only in terms of their technical skill but also in terms of professional behavior in the workplace and communication skills with real customers and within the project group. When students get assigned to more and more challenging tasks in the FIRMA, also getting good grades gets more challenging. With a good performance in a first and maybe simple project it is easier to get a good grade than with “just” good performance in a more challenging project later on. When we enable and support the
professional growth of students we also start expecting the students to take more responsibility of their project work.

After each project, students fill in the group and self-assessment form. First, they assess how the project went, then their own performance and finally the performance of all the other group members. The project assessment statements include:

1. Project group worked according to the project plan.
2. All project group members were active.
3. Roles and responsibilities were planned and communicated well.
4. Possible problems and obstacles were resolved successfully.
5. I am satisfied with the project outcomes.
6. Project group members communicated well.
7. Project group reached the project goal.
8. What went well in the project?
9. What would you do differently in the next project?

Statements one to seven are assessed numerically with a grade from 5 (I agree) to 1 (I do not agree). Questions 8 and 9 give the students the opportunity to express their opinion about the project’s success and reflect their own performance in the project. Answers are used for improving the FIRMA’s project process and project working policies.

Students assess their own performance in the project also by using the grading scale (see Appendix 1). Each of the four areas (Working in the FIRMA, Developing skills and applying them into practice, Organizational skills and Work performance) are assessed with a grade from 5 (excellent) to 0 (fail). Students also assess all their project group member’s using the same criteria that can be found in the rubric. The overall grade is the average of the student’s self-assessment and the grade the fellow students have given. The project manager’s assessment and opinion is taken into account as well as the customer’s feedback. Ultimately, the teacher is responsible in giving the students their grades.

**Experiences of the New Learning Process**

In general, students and teachers have been satisfied with the new learning process. Students think that the projects have now better “real working life feeling” than before. The new process is more meaningful and its clear description tells who shall do what and when. Students particularly like the new way of setting learning goals for the project together with the project group instead of each student filling in a learning diary monthly.

Better structure and responsibility definitions have also helped teachers to manage the increasing amount of students in the learning environment. However, the new process also has some shortcomings. First, collecting monthly hours for each student from the hour tracking worksheet is a huge effort for the student CEO. Second, reading through all self and group assessments for grading is a huge effort for the teacher. Therefore, an internal the FIRMA project has been started in which students design and implement a web-based hour tracking system that collects the monthly hours automatically for each student. As soon as the project is ready, students fill working hours in the system instead of using an Excel worksheet. Unfortunately, the hour tracking system will not solve the second problem, unless it will be extended to include also self and group assessments.
CONCLUSIONS AND FUTURE WORK

This paper introduced a project based learning environment, the FIRMA. The FIRMA is a good example of a learning environment that is able to provide learning experiences covering all the aspects of the C-D-I-O core model; also the Operate-phase which is often difficult to establish in the context of student projects in the field of ICT.

This paper also presented the FIRMA’s new learning and assessment process. We can conclude that the new learning process has several advantages. First, it keeps the focus of learning objectives in the correct topics considering, among other things, working life skills. Second, it provides students with more visibility to their learning progress in form of assessments and grades. Furthermore, a well-defined learning process also alleviates the work load of the teachers. In the future, the FIRMA’s learning process will be improved based on the feedback from both students and teachers.

REFERENCES


BIOGRAPHICAL INFORMATION

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**APPENDIX 1. THE FIRMA GRADING SCALE**

<table>
<thead>
<tr>
<th>Working in the FIRMA: Following agreed practices and working in a team</th>
<th>Excellent (5)</th>
<th>Good (3-4)</th>
<th>Satisfactory (1-2)</th>
<th>Fail (0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student successfully follows schedules and is often ready ahead of a time. Student works according to agreed practices and creates a positive atmosphere. Student works reliably in a team and encourages other team members. Student takes responsibility of the team’s work and schedules. Student uses work time wisely and prepares for his/her tasks.</td>
<td>Student can successfully follow schedules most of the time. Student works according to agreed practices. Student can reliably work in a team. Student uses his/her time methodically but may sometimes fail to do so.</td>
<td>Student arranges at following the schedule but sometimes fails. Student is able to work in a team, but often requires guidance. Student is passive: He/she does not take initiative but expects instructions and guidance.</td>
<td>Student does not follow the schedule. Student cannot work in a team. Student does not show any interest in the tasks.</td>
<td></td>
</tr>
</tbody>
</table>

| Developing skills and applying them into practice | Students actively shares information and finds out more information about working methods and practices. Student actively finds out about needed software and hardware. Student is able to develop his/her skills independently and is able to apply them into practice. | Student asks advice about working methods and practices when needed. Student is usually able to develop his/her skills and apply them into practice. | Student reacts to feedback but does not actively analyse or process the given information. Student does not search for information or apply it independently but waits for instructions and guidance. | Student neither reacts to feedback nor finds out about working practices. Student does not develop his/her skills. |

| Organisational skills | Student is able to analyse the FIRMA’s way of working (for example management and information sharing). | Student actively seeks for information about the FIRMA’s way of working (for example management and information sharing). | Student is able to follow the FIRMA’s way of working when instructed. | Student does not follow the FIRMA’s way of working. |

| Work performance | Student is able to work independently and accomplishes his/her duties excellent. | Student can work relatively independently. Student is able to accomplish his/her tasks sufficiently. | Student is somewhat able to accomplish his/her tasks, but needs a lot of guidance and instructions all the time. | Student is not able to accomplish his/her tasks. |
EXPERIENCES ON A MULTIDISCIPLINARY CDIO PROJECT

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ABSTRACT

Laurea, Haaga-Helia, and Metropolia Universities of Applied Sciences organized their first joint Professional Summer School Sprint on a multidisciplinary topic on wellbeing technology on summer 2016. The main idea was to gather multidisciplinary groups of students from each institute and their partner institutes for a two-week long service innovation seeking intensive course, provide them with real business problems from partner companies to solve, and to provide the students with modern tools and methods for co-creation and service design. This paper gives a brief introduction to how co-creation and service design were used as a learning environment, describes the results from the PSS Sprint 2016, and discusses about future development of the concept.

KEYWORDS

Wellbeing Technology, Project-Based Learning, Service Design, Co-Creation.
Standards: 3, 5, 6, 7, 8, 9, 10

INTRODUCTION

Laurea, Haaga-Helia, and Metropolia Universities of Applied Sciences organized their first joint Professional Summer School (PSS) with a title “Digital Wellbeing Co-creation and Start-up Summer School 2016” on Leppävaara campus on April 30 -- June 10, 2016. The main idea was to gather multidisciplinary groups of students from each institute and their partner institutes for a two-week long service innovation seeking intensive course, provide them with real business Design-Implement (CDIO Standard 5) problems from partner companies to solve, and to provide the students with modern tools and methods for co-creation and service design.

This event was initiated by the presidents of the universities as a part of enhancing cooperation between these three universities of applied sciences operating on the Helsinki
metropolitan area in southern Finland. The institutions have begun developing measures to promote student mobility and entrepreneurship education and help create easy-access programmes for innovation between higher education institutions and SMEs in the Helsinki metropolitan area.

In addition, there are collaboration efforts aimed at leveraging global funding channels for research and other projects more efficiently than before and creating Finland’s largest cluster for education exports in the UAS sector. The Professional Summer School is one of the seven development projects under way.

The partnership draws from each institution’s unique educational profile and identity. The Helsinki metropolitan area needs higher education institutions with distinctive profiles that respond to the region’s skills needs, both on bachelor’s and master’s degree level. To this end, the institutions are focusing on a strategic partnership that will benefit both students and employers. The joint efforts also serve as an excellent platform for building staff competence and faculty teaching competence (CDIO Standards 9 & 10).

This paper gives a brief introduction to how co-creation, service design, and open innovation were used as a learning environment, describes the results from the PSS 2016, and discusses about future development of the concept.

BACKGROUND

The idea of the Professional Summer School Sprint was based on Integrated Learning (CDIO Standard 7), open innovation, Living labs (http://openlivinglabs.eu/), and user centred design.

Open Innovation and the Living Lab operating model’s development are linked with the development of the post-industrial society, and they both emphasize on Active Learning (CDIO Standard 8). The Living Lab model was initially developed to understand people’s everyday objectives, needs and challenges and solve problems in their actual living and working environment. The starting points of new products, services and service processes are then the customer and market needs and the production of added value accordingly. The value experienced by the customer is an important criterion in assessing the usefulness of each innovation. The innovations created may be incremental or radical.

The Living Lab concept generally refers to a systemic, cyclic innovation, where all co-creation actors take part in the development and piloting of products, services, applications, technologies or new business models and policy programs. The parties responsible for product and service development usually take the development work through the following stages: background definition, brainstorming, and conceptualization, applying the concept in practice, creating prototypes, testing and further development, business model development and piloting, product launch and subsequent updating and further development. The role of end-users varies at different stages of the innovation activities and according to the purpose at each time (the innovation may be developed for, with or by the end-user). The results of the activities should correspond to the needs, goals and values of the customers/citizens/end-users.

With funding from the EU1 and nation states, Living Lab activities have developed into a widespread approach where international cooperation between end-users, research
institutes, cities and companies may also solve complex societal challenges, develop and pilot new business models and policy programs as well as create new jobs. In 2016 the Living Labs received the Innovation Luminary Award for best open innovation platform development. The quickly progressing effects of digitalization on health and wellbeing is simultaneously both a challenging change and a global business opportunity that can be reacted to by means of internationally scalable co-operation, also creating jobs. The Living Lab may also be a physical or virtual innovation platform or meeting place, such as the Professional Summer School Sprint or one of the technology platforms or digital applications used by different stakeholders, if the purpose is to enable multi-party co-creation and innovation.

The solutions created as results of the activities may be new or improved products, services and technologies or new, integrated or systemic solutions created using combinations of these. The resulting solutions may also consist of mutually supplementary social innovations, new operating concepts, business models or policy programs, if these are considered to produce added value for end-users. It can be said that, at their best, Living Labs strive for human-centric added value and innovations that are created by interaction between various actors in the ecosystem and mutually supplementary solutions and result in new markets and jobs. The assessment criteria for the concepts and solutions created as results of development challenges, development proposals, prototypes and activities depend on what new services or other solutions were pursued and how they can be developed in mutual co-operation.

Throughout Integrated Learning, open innovation, Living labs, and user centred design, the role of HEI and educational programs are evolving parallel to industrial and societal development. In this sense, the PSS Sprint operates as an important and valuable experimentation platform.

CONCEPT

The paradigm shift in marketing has highlighted the role of customer. Having been faceless objects, customers have become active subjects in the recent years, and customer orientation has become an essential topic in business operations (Kokko & Mäki 2009). The main issue in customer orientation seems to be the understanding that companies should focus on customer-perceived quality and solutions that better satisfy customer needs and expectations. These developments have impact also to educational sector.

From strategy and product development point of view, the summer school concept followed Blank’s (2012) and Kosonen & Doz (2007) line of thinking. Blank (2012) emphasize strongly customer involvement to strategy formulation and business creation activities in general. In Blank’s four step strategy formulation process, three first steps relate to capturing customer insight and only the last phase focused to business strategy process and strategy formulation. Kosonen & Doz (2007) underline the general agility of the company and the capability to transfer resources flexibly from less promising markets to areas with new possibilities. In general, companies overall ability to adapt change is one critical success factor (Vrontis et al., 2012; Mäki & Alamäki, 2014). The development, innovation and study processes at Sprint had a strong customer focus as a driving force to all actions. The participating case companies worked closely with the students and the Sprint concepts highlighted the interaction and data gathering from end-customers.
From the beginning, the idea for the course was to create an innovative new service concepts for the field of healthcare. Building upon earlier experiments, in particular Laurea Game Jam 2015, Laurea’s experiments in using Global Service Jam as a learning environment, and Metropolia’s strong background on CDIO based Intensive Projects, a decision was made to use a Design-process based approach to tackle problems introduced by real companies.

Design process is generally speaking an approach to problem-solving, framed in a nonlinear sequence of activities that utilizes creative thinking in problem solving (Tschimmel 2014, 5). Design process can be framed in a number of ways (e.g. Liedtka & Ogilvie 2011; Curedale 2013; Ambrose & Harris 2010; Brown 2009; Tschimmel 2012). The two-week session was framed to follow a future-oriented Service Innovation process model introduced by Ojasalo et al. (2015).

The selected process model was considered to be executable in a short time frame of two weeks long Design Implement Experience (CDIO Standard 5). While the process model is by nature an iterative instead of being linear, it was considered to be structured in a simple enough fashion to be split into a firm schedule that would be self-explanatory for the students to follow, regardless of their earlier experience of conducting such process. In addition, the authors of the process model give clear guidelines for the types of tools and methods applicable for each stage of the process (Ojasalo et al., 2015).

In Practice

The students were divided into small groups of 4 to 6 students and presented with a case assignment. Each group consisted of students from various disciplines to ensure cross-pollination of different viewpoints and different types of ideas. The participants’ educational backgrounds were numerous featuring students from curriculums in business management, social services and healthcare, business IT, facility management, electrical engineering, hospitality management, and business marketing to mention a few. Each morning the students were given guidelines as to what they should be focusing on next, as well as an introduction to the recommended tools and methods they might find useful. Mentoring was available for the students at all times, but the responsibility for planning and taking action to complete the project was on the students themselves. For the first week that focused on collecting insights of the users and understanding the problem space related to the assignment, the mentoring was taken care of by postgraduate students of Laurea UAS. During the second week which was more focused on developing a prototype of the final offering, the mentoring was mainly managed by teaching staff. The number of mentors per group varied. Due to practical reasons, some of the mentors stayed with the group from get go to the very end, while other groups only had mentoring available in the same room and on request, and not constantly focusing on their group. On a general level, one mentor was capable of managing three groups simultaneously, also highlighting the demand for the groups to do their work independently.

The emphasis of Professional Summer School Sprint was on learning through the case project. Lectures were kept short, and the lecturer and quests that gave speeches during the case project were instructed to keep their sessions shorter than one hour. The opening Monday was the only day that focused on lectures and instructions. After the teams received their assignments on Tuesday, the number of lectures was kept to a minimum to provide the students the opportunity to stay focused on their assignments. The lectures’ content was determined by the stage of the process, and the of each lecture was to give the students...
tools and new understanding that would be applicable in their case project. In early stages of the process the lectures focused on Service Design, user research methodology, methods of strategic foresight, ideation and prototyping methods. In the latter part the focus was more on framing the concept and marketing. Early on during the first week one of the lectures also focused on how to create an impactful pitch for a new service concept. In terms of the schedule, this particular lecture would have been more fitting for the second week, but as this particular lecture was also intended to raise the students’ spirit, it was scheduled for the first week.

During the first week, the students focused on learning more about their case assignment. They worked on field- and desktop research to learn about the end-users, the service providers business and the business environment, and the current and future trends in the field of their assignments. The first week concluded in students generating ideas of what kind of offering they might be prototyping during the second week. The second week focused on prototyping and business model generation, and finally pitching their newly created concept to the clients, the teaching staff, and other students.

The assignments were actual business- or customer problems that were introduced by both Finnish and international companies and public sector organizations. The assignments focused on a variation of topics related to digital health and wellbeing. The original plan for the assignments was to frame a problem without an obvious solution. Assessing by the outcomes of the assignments, assignments that filled this criteria were also the most suitable to be tackled using the selected process model intended for creative problem solving. The assignments featured tasks such as developing new digital solutions to ease the lives of cancer patients and their relatives, to develop a concept for a mobile eye hospital for developing countries, developing new digital offerings for a yoga studio, creating new time reservation concept for a communal public healthcare operator, and so on. Initially the plan was to allow the students to work on their own startup ventures as well, but this option was later limited to one group as a result of many of the registered students cancelling their participation and the demand to even the number of students in each group.

INTERVIEW RESULTS

Interview were conducted to get overall feelings and topics hidden under the surface. Student groups were interviewed on the middle of the second week. Since the answers started to repeat themselves and the groups were busy practicing their pitches, all of the groups were not interviewed.

“Tough but great”

First, the groups were asked simply to tell their current feelings of the course. One student's answer summarizes it all: “tough but great”. Everyone was saying that they have been learning a lot of new things, worked harder than what they expected, and have had a great experience.

Laurea students were already familiar with the service design methodology, but they found new aspects when they applied it in multidisciplinary group works. One Laurea student said that “This has been the best implementation of service design project she had ever been on”. All students agreed that the methodology they practiced during the course, would be very
effective tool also in other cases whether they are related to healthcare, business, technology, or any other discipline.

Students liked the change in teaching methods and pedagogy, and also were aware of the challenges when trying to balance control and given freedom on this kind of implementations. Some students would have liked to have more lectures and background, while the others would have preferred more group working. Some groups were happy about the amount of instruction and some felt it sometimes interruptive for the group work.

Students also mentioned that they gained new friends, holistic thinking, and improved their intercultural communication skills. Everyone liked the open, relaxed working environment. Some inspirational speakers, motivational mentors, and enthusiastic teachers got a high appraisal from students.

“*I found a reason for making mind maps*”

Second questions was about what students learned or achieved during this course. After working on a real life customer challenge on multidisciplinary group one student said: “This far I have been making these mind maps on courses because the teacher asked to do so. Working on this case I have found that it really is a valuable tool to get things done properly”.

Most of the students had their first experiences in working on a multidisciplinary and multicultural groups and thought that this would help them to face the future. Several teams also mentioned that they learned good tools for making innovations, which can be applied broadly in their future profession. One student joked that: “*I used to hate the word Innovation, but now I’m converted*”.

Some teams also mentioned gaining awareness of working between different cultures. Political correctness does not necessarily lead to good results, and therefore sometimes it would be acceptable to bend the rules.

Some groups pointed out that when they started to work on their case, they quite soon noticed that nobody had required expertise. However, they started working hard and were surprised to find that together they found feasible solutions to the current problem.

Some students felt they had learned a bit of entrepreneurial mind set. Some of them got curious to find out more by joining the Entrepreneur Society of their home institute. Presentation skills and fast prototyping were also mentioned. The interviews strongly indicate that the students’ personal and interpersonal skills, and product, process, and system building skills improved (CDIO Standard 7) during this Service Design based multidisciplinary Design-Implement Experiment.

“**Commitment**”

Third questions was about what should be changed, if anything, for the next time. All groups mentioned first the word Commitment. Few students disappeared at the middle and caused some challenges for the rest of the team. Fortunately the groups were big enough that missing one student did not cause much of a trouble for the rest of the group. Students suggested to have some control over the participation.
Some groups expected more supervision and appearance from the customer side in order to find out better their needs and desires. One group had only one phone conversation with the customer during the whole course. Students suggested that the customer companies should be trained more for the course to have more realistic expectations what can be done in two weeks. They also suggested that the company should send one of their employees to participate the course full time.

Sometimes when three groups were working on the same room, the noise level grew too high for some students to concentrate. This small problem was solved easily by moving into another space. Freedom on allocating their own space was highly appreciated.

Facilities worked rather well except that there were unexpected problems with wireless internet connection. Also they did not find enough of information about WLAN, printing, and some other practicalities. They suggested that next time would be a Q&A sheet summarizing the most common practical questions.

“Don’t change anything”

The last question was what should be the topic next time. Most common first reaction was “Don’t change a thing, this works really well”. Students wished that the multidisciplinary nature of the course would be kept. Also health-related topics with a twist to business and technology were also valued.

Some hot topics were mentioned: robotics, logistics, innovations, sustainability (several times), environment, IoT, recycling, social security, urban city, immigration and integration, tourism, medicine, social media and lifestyle, user experience, education, and future. However, they also said that the course name is currently very, very long.

“Thank you very much”

Interviewing the groups was an empowering experience. Students looked tired, but they still were smiling and in an excellent working flow. Most groups were thankful for getting an opportunity to attend this course.

Front-line managerial experiences

The ability to manage ambiguity turned out to be vital for Summer School Sprint management team. As a pilot experiment the team was unable to rely on earlier experiences and foreseeing what would and what would not work was difficult. The original plans were under daily adjustments and problems were solved as they occurred. Resilience to changes is afterwards seen as a fundamental characteristic to the front-line managers of such courses. Having a strong understanding of the Design-Implement process and ability to adapt to the situation and apply new methods when original plans were not producing desired results were necessary in order to cope with the ever-changing situation.

CONCLUSIONS

Laurea, Haaga-Helia, and Metropolia Universities of Applied Sciences organized their first joint Professional Summer School Sprint. The Sprint gave a true Design-Implement Experience for the students, and in improved their substance knowhow simultaneously with their personal, interpersonal, project, process, and system building skills.
Involving real companies to Active Learning experiences such as Professional Summer School Sprint improves the motivation of students, but it brings also challenges. For the next Professional Summer School, we will try to improve the commitment of the companies by focusing on a fewer number and improve our communication with the companies.

Student groups also suffered from no-shows and drop-outs. We will take some measures to give prospective students a better view on the course requirements, such that they would know how intensive course is and what is the depth of required commitment.

At the writing of this paper, the next Professional Summer School Sprint 2017 was under development. The last year’s experiences and especially student feedback will be used to improve the impact of the event. We also invite our colleagues worldwide to give suggestions, advice, and share experiences on similar activities.

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BIOGRAPHICAL INFORMATION

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CDIO-BASED ENTREPRENEURSHIP COURSES AS DRIVERS OF INNOVATION IN INDUSTRIAL SEGMENTS

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ABSTRACT

In this paper, we describe and discuss how in two CDIO-based entrepreneurship courses at Linköping University, Sweden, we encourage students to identify and solve challenges and problems in two adjacent industrial sectors, i.e., environmental technology and agricultural/green industries. Both courses are offered to a broad range of engineering programs. The industrial sectors chosen give the students a delimited context incorporating direction, business culture and technology, that forms a basis for the students on which to build their entrepreneurship cases. Working with real challenges gives real-life experience of how models and frameworks can be utilized and correctly executed. In addition, it increases project relevance, student motivation and learning.

One challenge to overcome is the fact that many students lack previous work-life experience and a thorough knowledge of the industrial sectors in focus. Experiences from earlier courses told us that this made it difficult for students identify and develop realistic, yet challenging and new business ideas on their own to. To remedy this, we tested facilitating interaction with industry, and through this help the students to detect real problems. Furthermore, it was anticipated that interaction with external actors, such as established businesses, organizations and potential customers, helps students to adjust and fine-tune needs and demands to create business ideas that could have real potential. As an added benefit, this approach could enable academia to act as co-creator in industrial problem solving, i.e., to put academic knowledge to practical use in society. Based on our own experiences and student feedback we discuss how this approach forced the students out of their comfort zones, challenged their creativity and enhanced their learning.

KEYWORDS

CDIO standards 2 (learning outcomes), 7 (integrated learning experiences) and 8 (active learning)
INTRODUCTION

In our teaching practice, we have realized that individuals learn and engage in problem solving in different ways (see e.g. Kolb, 1984, who discusses different problem-solving styles). Through a mixture of different teaching approaches, more students can be addressed and reached in ways that fit their individual ways of learning (see e.g. Garrison and Kanuka, 2004; Ginns and Ellis, 2007; Lopez-Perez et al., 2011). This can be done in several ways such as creating a mixture of traditional lectures, seminars and workshops, films and e-learning that facilitate independent study. Through our practice, as well as from theory, we have realized that both relevance and the “fun factor” are important motivators that improve learning (MacInnis, Ramsden and Maconachie, 2012; Norman et al., 2014; Norrman et al., 2016). These findings led us, in a previous project, to develop a model for learning, the ERL model (Expanded Room for Learning) (Norrman et al., 2014), which has now been implemented in several of our courses. The ERL model puts the learning objects in focus and emphasizes that the teaching design is influenced by the stakeholders (e.g. teachers and students), pedagogics and technology (e.g. the mix of teaching approaches and the ICT tools used), and context (e.g. setup and cases).

In this paper, we put our focus on the context factor of the ERL model as this is important for the learning process. In addition, the CDIO framework (see e.g. Crawley et al., 2014) emphasizes the importance of relating learning to a context, as it increases understanding, motivation and relevance. This is also important for achieving quality learning by means of what Biggs (2003) terms conditional and functional knowledge or, as expressed by Crawley et al. (2014) the engineering students’ ability to engineer. In the courses that form empirical cases for this paper, we have used the chosen contexts to incorporate direction, business culture and technology, which form a basis for the students on which to build their entrepreneurship cases.

Another important aspect is entrepreneurial learning, as this could be utilized in teaching to enhance both learning as such and knowledge about entrepreneurship. Our ambition is not to push (all) students into business venturing, but merely to foster a more business-oriented mindset, which they could benefit from regardless of where they end up after their education. According to Cope (2003), the learning process of entrepreneurs is action oriented and experience based, i.e., entrepreneurs use “learning by doing” strategies, which are about trial and error, problem solving and discovery. This is also shown by McGrath & McMillan (2000), who stress that an “entrepreneurial mindset” incorporates passionate opportunity seeking, tenacity and execution focus in idea realization, and the ability to engage energy from people around them. Politis (2005) stresses that entrepreneurial learning is synonymous with experimentation. One problem though, according to Gibb (2002), is that most university courses related to entrepreneurship focus on learning about entrepreneurs and entrepreneurship rather than learning for entrepreneurship, or the above-described “entrepreneurial learning.” Gibb argues that this needs to be changed and that the focus ought to be on giving the students tools that could be used in later entrepreneurial processes and to create more activity-based learning where they can gain experience.

To us, as teachers in entrepreneurship courses for engineering students, it is a challenge to make our students engage in real and relevant tasks. In our lectures as well as in our seminars and workshops, we strive to encourage creativity, courage, experimentation and an attitude towards problems that is in line with what we found written on a wall at Stanford Ventures in 2012: “Every problem is an opportunity - the bigger the problem, the bigger the opportunity.” Like Gibb (2002), we strive to encourage entrepreneurship and entrepreneurial
learning and we want our students to acquire practical tools useful for entrepreneurship, rather than theoretical knowledge about entrepreneurship. Our main goal is to encourage experiential learning, which is in line with the CDIO goal that the engineers should be able to engineer (Crawley et al., 2014). Without experience during their studies, they will only get theoretical knowledge. Another mission is to support the role of universities as co-creators rather than knowledge banks (see e.g. Frankelius and Norrman, 2013) and encourage entrepreneurial experimentation, both among our students and ourselves, i.e., we want to learn together with our students.

In some courses this is solved by letting the students work with real-life cases (see e.g. Creed et al., 2002), which has been tested previously in a course (TEIO20) that forms one of the cases in this paper (see Norrman et al., 2014). However, during recent courses, this approach was abandoned due to several reasons: First, it is both time consuming and difficult to find business cases that work in courses and are owned by firms that are willing to leave them in the hands of students. Second, even if cases are found and even if the idea owners assure in advance that their participation can be assumed, this is not always the case in practice. The result of this is that the conditions, by the students, are regarded as unfair as some groups get dedicated idea owners and other get those that care less. Third, when comparing the engagement and student satisfaction in the courses (TEIO20 that had cases, and TKMJ49 that was run on the students' own ideas), we realized that the students preferred to work with their own ideas. However, to make this work, previous experience has taught us that it is important to guide the students into a specific context, as this helps them to focus and prevents them from going for low-hanging fruit (e.g., they create an app, financed via advertisements, and conduct market investigations among their close friends).

A challenge, when choosing a context to relate the teaching and learning process to, is the fact that many students lack previous work-life experience and a thorough knowledge of the industrial sectors in focus. Experience from previous courses has told us that this made it difficult for students to identify and develop realistic, yet challenging and new business ideas on their own. To resolve this, we have tested facilitating interaction with industry, and through this help the students to detect real and relevant problems.

Furthermore, it was anticipated that interaction with external actors, such as established businesses, organizations and potential customers, helps students to adjust and fine-tune needs and demands to create business ideas that could have real potential. As an extra benefit, this approach could enable academia to act as co-creator in industrial problem solving, i.e., to put academic knowledge to practical use in society. Based on our own experiences and student feedback we discuss how this approach forced the students out of their comfort zones, challenged their creativity and enhanced their learning.
University research and education and their role and contribution to regional and business development have been debated for more than two decades. Concepts such as triple helix (Etzkowitz, 2000) are being extensively used to describe joint efforts for regional economic development, and the so-called “third mission” of universities to contribute to economic development is becoming more and more established. The third mission adds to the more traditional roles of research and education. Recent streams of literature suggest looking beyond this third mission and promote a fourth mission, the mission of co-creation (Trencher et al., 2014). This would mean a development from the entrepreneurial university to the transformative university in which universities collaborate with diverse societal actors in development of specific locations, regions or societal sub-sectors. This is in line with Frankelius and Norrman (2013), who claim that there is a need to enlarge the role of academia in innovative processes. Academic research can lead to innovation and in order to stimulate this development, policy focuses on commercialization of research projects. In addition, student-driven entrepreneurship is encouraged, while the universities support trade and industry with well-educated workers. In these cases, academia is regarded as the source from which innovation springs, develops and is diffused. However, far from all new ideas are born inside universities - sole inventors as well as industry contribute a major share of ideas generated. Along with Frankelius and Norrman, we argue that the role of academia in the innovation process can be enlarged through increased cooperation with surrounding industry, i.e., ideas from outside the universities can be developed and refined e.g. by students and then continue their development towards commercialization outside academia. This type of interplay adds relevance and meaning to education and allows students to gain real-life experience during their studies, which is in line with the CDIO approach.

METHODS AND APPROACH

In this section, we present the general design of the two courses from which we draw our experiences and give a deeper description of the approach with inspirational seminars. We also report how we surveyed students’ experiences of taking part in the courses in general and inspirational seminars in particular.
To start, this experiment used two existing courses; “Entrepreneurship and New Business Development” (TEIO20) and “Environmentally Driven Business Development” (TKMJ49). Both courses are offered to various engineering programs at Linköping University and students generally take these courses in their fourth or fifth year of study. This year the first course (TEIO20) had a focus on the agricultural sector and the second (TKMJ49) focused on environmental technologies. Both courses introduce and use a number of theories and tools for entrepreneurship and business development, such as NABC (Carlson & Willmot, 2006), business model development (e.g. Osterwalder and Pigneur, 2010), Porter's five forces analysis (Porter, 2008), SWOT (Strengths, Weaknesses, Opportunities and Threats), etc. These approaches and tools were presented in lectures followed by interactive seminars in which the students applied the theories and tools to their own business ideas. During the course the business ideas were developed and refined and documented in a report. Students were also encouraged to go out and interact with external actors such as presumptive competitors and customers, in order to verify their ideas and value propositions. At the end of the course, the business ideas were presented in an exhibition at which the students invested toy money on what they perceived as the best ideas, and a winner was selected. We also used an external jury with business people from the region who gave a prize for the most promising idea.

To help students in formulating ideas to be developed we arranged inspirational seminars at the start of the courses. For the course focusing on the green (agricultural) sector (TEIO20) we brought the students to Vreta Kluster, which is a meeting place and development arena for technology and business development that contributes to the green sector’s development and growth. For the other course (TKMJ49) we visited Cleantech Östergötland, a network of environmental technology companies. To both seminars, we invited experienced entrepreneurs who made short presentations describing challenges they saw in their line of business. Based on the challenges given, groups of four or five students jointly started to...
formulate business ideas aimed at solving selected problems. In forming the groups, students were instructed to mix with individuals from other engineering programs to broaden the team's experiences and interests, e.g. mixing industrial economics with environmental engineering. During problem formulation and idea generation, the invited industry representatives served as coaches and helped the students in the initial formulation of a first business idea. The ideas were then further developed and refined throughout the courses as described above.

For assessment of the chosen approach with inspirational seminars, we used a number of complementary sources of information. First, we used an online survey focusing on the inspirational seminars sent to the students after the courses were complete. The students were asked to give input on strengths and weaknesses with the seminars. We also used personal reflections written by each student on their learning outcomes of the full course. Finally, we used online course evaluations that students fill out for each course they take at the university.

From the students’ answers and reflections, we summarized their experiences and looked for quotes describing different views on the seminars. The analysis was quantitative because of low response rates (10-30%). In any event, we found 30 comments on the seminars. All comments were classified as being positive or suggestions for improvements/negative. Furthermore the theme for the comment was noted (e.g. if it was about involvement of external actors, learning about industry challenges, etc.).

**STUDENT ATTITUDES TOWARDS THE INSPIRATIONAL SEMINARS**

Of the 30 identified comments on the seminars, six could be labeled as suggestions for improvements/negative and 24 were positive. The negative comments/suggestions for improvements dealt with issues regarding better instructions to speakers and students before the seminars and more support in the workshop when the students started to develop their ideas.

Of the positive comments 11 students mentioned that the setting of the seminars as such created an inspiring context and a good start for the courses. Below we have displayed some of the quotations:

- “Inspiring, informative, a great way to start the course”
- “The seminar at Vreta Kluster was very interesting and rewarding - keep this step in the course.”

Another seven comments were about the opportunity to meet external actors such as industrial representatives and business development coaches. It was also appreciated that they could learn about the industry as such and the problems the industry was facing now.

- “The “pitch day” at Vreta Kluster was funny. It was interesting and rewarding to get insight in the industry segment that was target for our business idea development.”
- “Interesting to hear from those that are working in the industry”

A few commented that they liked the way of working (such as using Lego and coaching from industry representatives) which was new to them.
“It gave perspective on obstacles that companies deal with in their daily work and it was a good occasion to talk more to other course participants and the firm representatives about the business idea proposal.”

Finally, we got some comments that suggested matter for improvements:

- "More help in the idea generation process - if you are not able to come up with an interesting idea you risk falling behind in the course"
- "Connect the speakers even more clearly to the course content"

**ANALYSIS AND CONCLUDING DISCUSSION**

Firstly, we can conclude that letting the students meet with representatives from the industrial sector was appreciated by most students. However, to make the concept work smoothly, careful planning and preparations are key. At our first try, the seminar at Vreta Kluster, six speakers were invited and they were told to give evidence of problems in the agricultural sector. The seminar was announced publicly and invitations were sent out to a broad range of actors. The oral comments during the seminar and shortly afterwards were that the speeches were interesting and that the students found it inspiring to get knowledge about farming. Unfortunately, they had problems in transferring the problems into needs and approaches that could form new business ideas within their own disciplines where they could utilize the domain knowledge acquired during their education. Some of the groups took on the mission and succeeded, but about one-third of the groups ended up in problems outside their own knowledge domain, e.g. in low-tech or retail-based business ideas such as meat boxes, internet forums for farmers, automatic milk stands or small-scale vegetable markets. About one-third of the groups found ideas where they could make use of their engineering skills in biology and chemistry and came up with ideas using sensor technology for watching crop-drying processes, using bio-pesticides for keeping insects away from plants or using hydro-optic systems for growing plants indoors, etc. The remainder were on a scale between high-tech and low-tech.

The seminar at Cleantech Park took place a couple of months after the Vreta Kluster seminar. Here we had the advantage that most of the students had taken several courses in environmental technology, and through this had a basic understanding of the cleantech industry. Another advantage was that the invited guests were representing technology-based firms, i.e., they had a shared background with the students.

In January 2017, another round of TEIO20 was started, and this time too we decided to start the group work with an inspirational seminar. Since we had the two previous trials from 2016 to start from, the approach was changed a little bit. First we prepared the students better, already at course start. They also got a presentation displaying about 100 problems collected from questionnaires used in a research project concerning innovation in the agricultural sector. Finally, the students were encouraged to start out from their own knowledge domains and try to come up with problems and solutions from that point of view. The representatives from the agricultural industry (one researcher and two crop growers) were informed that they would meet with students in innovative computer programming, mechanical engineering, biotechnical engineering, chemical engineering and engineering physics. The seminar was held at LiU and the farmers gave a short overview of the technology development in farming and showed pictures of the tractors they started with and the ones they use now in their own farming business. They showed pictures generated from harvesters and N-sensors and
talked about software systems for precision agriculture. The researcher gave an overview of how UAVs could benefit the farming industry. After the presentations, we continued with group work, where the guests mingled with the students. The ideas that popped up were technology-based to a higher extent than previously.

One factor that can affect how seminars like this work and are perceived by the students is the number of participating students. At Vreta Kluster there were about 60, divided into 12 groups; while at Cleantech Park there were 15 who worked in three groups and at LiU Campus there were 25 students working in five groups. The atmosphere was more intimate and less stressed at Cleantech Park and at LiU Campus due to the smaller number of participants, which may have allowed for more questions. At Vreta Kluster everything was new, the students arrived by bus to an unknown environment, and not all external participants were presenters, and were thereby not recognized as possible sources of knowledge by the students. As teachers we did our best to toss the groups together with different industry representatives, but still it was a very large event to handle.

It should be noted that the arrangements that were done in TEIO20 and TKMJ49 in 2016 required resources that exceeded the original course budgets. This was possible since we had external funding to develop our pedagogics. However, in TEIO20 2017, the seminar was arranged without using any extra resources besides the contact network of the teacher. Irrespective of economic resources teachers wanting to do similar things should have a broad network with industry representatives or start collaborating with industry associations, science parks, etc. to be able to pick suitable individuals who want to interact with students.

Future development of the concept could include better preparation for both students and industry representatives and that industry representatives come back and give feedback on the business ideas after they have been developed a bit.

Further, we believe that this approach could be a good way of bridging the gap between academia and industry. Using students in collaboration projects not only gives relevance to education and enhances learning, but it is also an attractive and low-cost way of starting collaboration with industry which later can result in new product or business development and joint research projects (see Hjelm and Lindahl, 2016). Finally, an underlying ambition is that our courses could create continual entrepreneurial activities generating both new startups and well-equipped engineers, taking advantage of their entrepreneurial mindset in their employment. Given the short period after these recent experiments in our courses, this is not yet possible to evaluate, but could be an interesting topic for further examination.

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CDIO BASED ENGINEERING DESIGN AND OPTIMIZATION COURSE

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ABSTRACT

In order to design competitive products that meet today’s challenges, future engineers need knowledge and experience in applying and integrating optimization theory in the engineering design process. The Chalmers course Engineering Design and Optimization addresses this need and was developed and first offered in the fall semester of 2013. This paper provides a detailed account of the course development experiences, teaching methods and course evaluations using CDIO Standards. It also includes a discussion of the learning objectives, required resources, instructional processes and student assessments. The course is analyzed to see to what extent the course aim is satisfied and highlight areas of improvement. Three projects are carried out in groups of two students. The projects are a cantilever design-build-test exercise, a redesign project that involves material selection, and a multidisciplinary design project of an engine component using multi-physics software. The assignments are assessed with respect to both engineering criteria as well as reporting and communication. The course is believed to be novel in the way optimization theory and tools are taught as an integrated learning experience with engineering design and physical prototyping. The course has had a great impact on the students’ choice of master’s thesis project. The number of optimization-focused master thesis projects has increased from two or three to around 15 annually. Several of these projects are multidisciplinary and joint projects between departments of Applied Mechanics and Product & Production Development. The course has also initiated a valuable partnership with industry on optimization that now has grown to a network with 20 industrial and academic members.

KEYWORDS

Optimization, Engineering Design, Design-Build-Test, CDIO Standards: 2,5,6,8
INTRODUCTION

Optimization has been used in industry for decades to cope with the increasing needs to design and develop competitive products that offer profitable business propositions. As the engineering systems in sectors such as the automotive and aerospace industries become increasingly sophisticated and intra- and inter-connected, multidisciplinary design optimization (MDO) has emerged as the engineering design support tool for managing, and eventually exploiting, these complicated interactions to cope with more and more stringent, and typically competing, requirements, see, e.g., (Brophy F., 2009; Haar & Brezillon, 2012; Lagloire, 2014; Piperni, DeBlois, & Henderson, 2013). Moreover, the societal challenges in the next few decades are huge, e.g., the growing population requires more efficient use of material and other resource. It is the responsibility of engineers to find optimal solutions to use resources more efficiently. While research in optimization has made significant advances in theory and algorithms to address different types of optimal design problems, optimization is still not a ubiquitous part of engineering curricula. Teaching and employing optimization theories, methods and techniques to help future engineers learn how to weigh constraints and criteria against one another and select best possible design solution should be a vital part of any engineering education.

Since the five-year program in mechanical engineering (ME) at Chalmers University of Technology is a CDIO program (CDIO, 2017; Crawley, 2007), there already existed several design-build-test product development projects in which the students realize a product from the need to a functional model or prototype. However, until a few years ago the program lacked an educational event in which students trained and learned to use algorithms, methods and software to optimize a product/system. This was true despite the fact that there existed several elective courses on optimization given by the mathematical sciences department, possibly because those courses focused on theories and algorithms, rather than methods and applications, and very few ME students took those courses. Consequently, the students have mostly practiced trial-and-error methods in combination with simulations to find “good enough” solutions before going to prototyping. A more up-to-date strategy would be to use a more systematic approach based on analysis, simulations and optimization to find optimal solutions. To address this gap the ME program has, for the bachelor part, designed its own simulation-based math education including basic optimization theory and algorithms (Enelund, 2011) and applied optimization in basic mechanics. While for the master’s level a new interdisciplinary course was developed called Engineering Design and Optimization, which for three years has been an elective for students studying Applied Mechanics, Automotive Engineering, Engineering Materials and Product Development. This course teaches practical approaches to design optimization, guiding the students through different ways to apply algorithms and tools to find the best possible solution to a design problem with some objective or set of objectives, highlighting hands-on experience with addressing different types of problems, along with specific ways that economic, environmental, and social sustainability needs can be accounted for in a design optimization context.

This paper aims to bring forward experiences from the development, teaching and evaluation of the Engineering Design and Optimization course. In particular, the paper aims to

- provide a detailed account for course development experiences involving faculty from different departments, teaching methods and course evaluations,
- provide a discussion of the learning objectives, pedagogy, resources and instructional processes, as well as assessments and course evaluation,
• analyze the results to see to what extent the course aims and goals are satisfied and to discuss whether the intentions of the course have been realized?
• discuss in what way the students are better prepared to find optimal solutions in the development of products and systems?

The content of the paper is structured as follows: First we describe the course including the intended learning outcomes, course aim, teaching activities and assessment. The three project assignments are then further on described in some detail and discussed. Student course evaluations together with input from employees and alumni are used to determine to what degree the course goals have been achieved. Finally, the findings from this analysis together with a summary of the experiences from the course including challenges and success factors are discussed.

COURSE DESCRIPTION

The Engineering Design and Optimization course is given jointly for the master’s programs Applied Mechanics, Automotive Engineering, Product Development and Materials Engineering at Chalmers University of Technology. These master’s programs are all independent programs and integrated parts of the five-year program in mechanical engineering. This means that the course has a mix of students from different backgrounds at Chalmers along with additional students joining from different universities worldwide. The size of the course is 7.5 ECTS (European Credit Transfer System, where 1.5 ECTS corresponds to 40 working hours) and runs over a nine week period.

Approximately five years ago the need for an engineering design course in combination with optimization was identified by the dean of education and the program faculty. Key elements were discussed, identified and agreed upon, such that the course should be built around several integrated design-build-test projects with elements of multidisciplinary, simulation-driven design and optimization. The program advisory board with representatives from industry as well as the Chalmers educational management welcomed the initiative and supported it. A working group with engaged and committed faculty from three departments (Applied Mechanics, Materials & Manufacturing Technology and Product & Production Development) was assembled. The working group was led by the head of the ME program and a development budget was given by the Dean of Education. The budget made it possible for the faculty to put a significant number (about 200) of working hours in the development. The guiding principles of the course development were CDIO (e.g., Standard 2 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, Standard 5 Design-Implement Experiences, Standard 6 Engineering Workspaces and Standard 8 Active Learning) and constructive alignment, i.e., aligning intended learning, teaching activities and assessment (Biggs, 2007).

The working group began by formulating the course aim and entry requirements. The entry requirements were chosen to be broad, advanced and active within product development, programming, simulations, materials and mechanics. Next, intended learning outcomes (ILOs) were formulated based on the aim of the course, entry requirements and input from students, faculty and industry. The learning outcomes were then presented and scrutinized at program faculty meetings and links between the course and the programs were discussed and established. After about six months of development work, the course was launched and delivered to around 40 master’s students in quarter one of the fall semester of 2013. Since
then the course has been annually reviewed and refined with respect to learning outcomes, teaching activities and assessments.

**Course aim**

The course aims at integrating traditional design methodologies with concepts and techniques of modern optimization theory and practice. With this approach the students are expected to learn to create design solutions that are creative and have better performance (e.g., lighter, stiffer, more reliable etc.) compared to traditional methods. Specifically, the course aims to:

- Demonstrate a selection of different tools and methods for optimization of mechanical products and structures,
- Demonstrate a design process for improvement of components in products and mechanical systems,
- Demonstrate the iterative nature of the development chain including modeling-analysis-test,
- Use and familiarize students with modern CAE tools, and
- Demonstrate how to incorporate material selection as a part of the product development process

**Intended Learning Outcomes**

The intended learning outcomes (ILOs) describe students expected knowledge, skills, and attitudes after completing the course as shown in Table 1.

<table>
<thead>
<tr>
<th>ILO</th>
<th>Description</th>
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<tbody>
<tr>
<td>ILO1</td>
<td>Show ability to master the complete development chain including modeling-analyses-test-evaluation</td>
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<tr>
<td>ILO2</td>
<td>Identify areas for improvement in a new or an existing product design</td>
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<tr>
<td>ILO3</td>
<td>Identify and choose appropriate material alternatives for a product</td>
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<td>ILO4</td>
<td>Apply previously-learned design methods and tools to practical problems</td>
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<td>ILO5</td>
<td>Create appropriate simulation models of the design problem</td>
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<td>ILO6</td>
<td>Use Computer Aided Engineering (CAE) tools to design and simulate product performance</td>
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<td>ILO7</td>
<td>Formulate design optimization problems based on project or product requirements</td>
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<td>ILO8</td>
<td>Apply numerical optimization techniques and computer tools to solve optimization problems</td>
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<tr>
<td>ILO9</td>
<td>Interpret optimization results for design decision making (e.g., material selection, geometry, manufacturing)</td>
</tr>
<tr>
<td>ILO10</td>
<td>Create CAE drawings for use with three-dimensional printing tools</td>
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<tr>
<td>ILO11</td>
<td>Iterate on design solutions to continually improve a product's design and performance</td>
</tr>
<tr>
<td>ILO12</td>
<td>Communicate design solutions, including rationales for a given choice, advantages, and disadvantages over alternatives</td>
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</tbody>
</table>

The Conceive, Design and Implement Stages of CDIO are explicitly formulated in the ILOs. The Operate Stage is manifested in project assignments one and two and included in ILO1 and ILO2. In project assignment one the students manufacture and test their design solutions while project assignment two starts with scrutinizing the failure of an existing consumer product.
Course structure

The course contains lectures, exercises, project assignments (PAs), workshops, a written midterm and a final exam, see Table 2. The course emphasizes on teaching the students about optimization and how it can be integrated in the design and product development process. This is realized through mixing theory lectures together with specific workshops where software and optimization applications are exercised. The course involves an introduction and training in optimization software, where the students are introduced into the topic via traditional lectures, guest lectures and workshops. There are additional recorded video lectures which are both theoretical and training videos on how to operate certain software. These videos are uploaded on Chalmers’ learning platform to be easily accessible for the students. The course has intentionally placed a majority of the lectures early in the course in order to support the students’ progress with the three project assignments, see Table 2.

Table 2. Number of teaching activities per type for each study week

<table>
<thead>
<tr>
<th>Study Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
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<tr>
<td>Teaching Activity</td>
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<tr>
<td>Lectures</td>
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<td>4</td>
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<td>PAs sessions</td>
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<td>Workshops</td>
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<tr>
<td>Midterm and Final Exam</td>
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</table>

Teaching and Learning Activities

The course structure is divided into a number of activities which are carried out during the nine-week schedule. The activities include: traditional classroom lectures, industrial guest lectures, project assignment instructions, and workshops. The traditional lectures begin with an introduction to the engineering design process and iterative design-build-test loops. Next, optimization is introduced with a focus on how to formulate optimization problems and the principle concept of different algorithms. The lectures that follow present deeper dives into optimization in the context of applied mechanics, materials selection, multi-objective problems (MOO), design for quality, design for sustainability, and multi-disciplinary systems design. Efforts have been made to align the lectures to the project assignments and workshops so that the student can quickly move from working with theoretical concepts to hands-on implementation and practice. The Industrial guest lectures are used to give a broader view of optimization in industrial contexts and also to highlight the current state of art implementations in industry.

The main course literature is the textbook “Principles of Optimal Design - Modelling and Computation” by P.Y. Papalambros and D.J Wilde (2000) accompanied by texts on topology- and structural optimization (Bendsoe & Sigmund, 2003; Christensen, 2009). The engineering design processes and aspects are mainly inspired from (Pahl, 1996; Ulrich, 2008)

Learning Assessments

The course contains three mandatory design projects, midterm and final exam which together constitute the assessment and build up to the final course grade. The links between intended learning outcomes, teaching activities and the assessment are illustrated by the Course design matrix in Table 3. A closer look at the matrix reveals that the project
assignments may be regarded as the corner stones of the course as they cover the full spectrum of the ILOs.

Table 3. Course design matrix. L=lecture, GL=guest lecture, W=workshop and PA = project assignment.

<table>
<thead>
<tr>
<th>Teaching and Learning Activity</th>
<th>Intended learning outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1 Introduction &amp; general engineering approach</td>
<td>1 2 3 4 5 6 7 8 9 10 11 12</td>
</tr>
<tr>
<td>L2 Introduction to optimization</td>
<td>X</td>
</tr>
<tr>
<td>L3 Applied mech. structural dynamics, FEM</td>
<td>X</td>
</tr>
<tr>
<td>L4 Modelling</td>
<td>X</td>
</tr>
<tr>
<td>L5 Optimization algorithms &amp; tools</td>
<td>X</td>
</tr>
<tr>
<td>L6 Material selection &amp; evaluation</td>
<td>X</td>
</tr>
<tr>
<td>L7 Concept &amp; Embodiment Design</td>
<td>X</td>
</tr>
<tr>
<td>L8 Applied mech. Structural design optimization</td>
<td>X</td>
</tr>
<tr>
<td>L9 MOO &amp; trade-off analysis</td>
<td>X</td>
</tr>
<tr>
<td>L10 Fatigue and age-based failure</td>
<td>X</td>
</tr>
<tr>
<td>L11 TRIZ</td>
<td>X</td>
</tr>
<tr>
<td>L12 Applied mech. Topology opt. applications</td>
<td>X</td>
</tr>
<tr>
<td>L13 Quality &amp; uncertainty management</td>
<td>X</td>
</tr>
<tr>
<td>GL1 Applied Optimization- ANSYS</td>
<td>X</td>
</tr>
<tr>
<td>GL2 Topology optimization in automotive</td>
<td>X</td>
</tr>
<tr>
<td>GL3 Optimization in practice (Aerospace)</td>
<td>X</td>
</tr>
<tr>
<td>PA1 PA1 Introduction and tutoring</td>
<td>X</td>
</tr>
<tr>
<td>PA1 PA1 Cantilever Challenge Live Competition</td>
<td>X</td>
</tr>
<tr>
<td>PA2 PA2 Introduction and tutoring</td>
<td>X</td>
</tr>
<tr>
<td>PA2 PA2 group presentation</td>
<td>X</td>
</tr>
<tr>
<td>PA3 PA3 Introduction and tutoring</td>
<td>X</td>
</tr>
<tr>
<td>PA3 PA3 Simulated engineering briefing meeting</td>
<td>X</td>
</tr>
<tr>
<td>W1 Optimization Using MATLAB</td>
<td>X</td>
</tr>
<tr>
<td>W2 Material Selection with CES Edupack</td>
<td>X</td>
</tr>
<tr>
<td>W3 Metamodeling-Design of Experiments</td>
<td>X</td>
</tr>
<tr>
<td>W4 Reverse Engineering</td>
<td>X</td>
</tr>
<tr>
<td>W5 Multi-objective optimization in MATLAB</td>
<td>X</td>
</tr>
<tr>
<td>W6 COMSOL Workshop</td>
<td>X</td>
</tr>
<tr>
<td>W7 Mathematical Exercise Workshop</td>
<td>X</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Learning Assessments</th>
<th></th>
</tr>
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<tbody>
<tr>
<td>PA1</td>
<td>X</td>
</tr>
<tr>
<td>PA2</td>
<td>X</td>
</tr>
<tr>
<td>PA3</td>
<td>X</td>
</tr>
<tr>
<td>Mid-Term Exam</td>
<td>X</td>
</tr>
<tr>
<td>Final Exam</td>
<td>X</td>
</tr>
</tbody>
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**PROJECT ASSIGNMENTS**

In the early development of the course it was decided to have a strong emphasis on fast design iterations and to focus design activities on embodiment design and detail design phases rather than conceptual design. In other project-based courses in the mechanical engineering curriculum it is common to run projects with a broad design scope usually positioned in the early phases of the design cycle. Commonly the students are well introduced to the conceptual design phase, however, a frequent experience is that there is not enough time to work with the embodiment design and detail design phases where the
system boundary and architecture have already been predefined. Still the backbone of the assignments is the full design-build-test process based on the CDIO standard 5.

The three projects in the course are:

1. Cantilever challenge - Introduction to design-build-test cycle and topology optimization
2. Redesign, material selection and optimization of a failed product
3. Multi-objective optimization
   a. of a vehicle suspension system in MSc Adams (course rounds 1 and 2)
   b. of an engine encapsulation component (course rounds 3 and 4)

In the following sub-sections the details of the assignments will be described in more detail.

**PA1 - The Cantilever Challenge**

In the first assignment the students are introduced to the design-build-test design cycle as well as topology (TO) and shape optimization. The specific design task is to create the lightest and stiffest cantilever beam possible given a specific design domain and load condition. The assignment is presented to the students after the first lecture on Monday morning the first study week. The ambition is to get the students involved early on in the course, however, this leads to a dilemma since almost no course material have been presented yet the first day. This is handled by separating the first project into two main design iterations. In the first part of the project, see Figure 1, the students are given the design domain, performance objective function, constraints and material properties. They are further on asked to, together with a peer student, design the best possible cantilever beam they are capable of based on their previously gained knowledge and experience. The deadline for the first iteration is on the Wednesday the same week, hence they have to complete the task in two days. A high level of instructive process guidance is given including suggestions on how much time to spend on each sub-task in the design loop. The design loop is defined as five main steps; Requirements evaluation, design sketch, CAD model, FE analysis and finally performance evaluation. The delivery for the first iteration is a one page PowerPoint slide including the initial design sketch, CAD model, FE analysis and the resulting performance number.

After completing the first iteration the students are given a lecture and one workshop tutorial on topology optimization. Essentially they are handed a new and more powerful tool to apply in the second part of the project. Due to the limitation in time it is not possible to provide tutorials and lectures in order to conduct topology optimization in 3D. Hence more simple 2D software are presented. The first is the BESO2D topology optimization software developed by RMIT University in Melbourne (2017). The second is the 2D version of ANSYS Mechanical Optimization tool (ANSYS, 2016). The students are also encouraged to download the TO app TopOpt developed by DTU (2017).

One of the key perspectives that is emphasized during the project is that design optimization essentially is an automated version of the design-build-test cycle that the students performed manually in the first part of the project. Most students perform more than 10 iterations, and possible due to the competition, compare performance results with other groups. Five days before the competition the students submit the final beam design. The models are checked for CAD modelling errors and gets 3D printed in a solid acrylic polymer. For the competition an experimental test device have been developed in order to easily mount each cantilever beam and apply the 100 N load. The mass of the beam is measured using a laboratory scale and the deflection is measured using a dial indicator. The data is inserted into an excel score
board displayed via a projector so that all the students can track who is leading the competition. The test results are discussed in class with regards to simulation validation based on their predicted deflection and performance from the FE simulations. In some cases the students have not considered elastic (local) buckling leading to beams not being able to withstand the load.

Figure 1. Illustration of the two-stage iterative design process in the first assignment.

PA 2 - Redesign, material selection and optimization of a failed product

The second assignment begins from the standpoint of the “Operate” area of the syllabus. In the early development of the course there was an idea to integrate questions regarding product and component failures. Failures both related to our everyday life as well as in industry. The fourth stage Operate in the syllabus incorporates sub-areas such as recycling, upgrading and system improvement. The PA2 assignment hence begins with asking the students a few days before the official start of the project to come up with their own example of a product or component that has failed. The students then make suggestions and the problem is discussed with the supervisor in order to judge if the problem is solvable and suitable to fit the objectives of the assignment in terms of, most importantly, modelling feasibility with respect to the project time frame.

For the students who are unable to find an example, the supervisor has two-three predefined examples at hand. The examples have been a bike lock, fridge door handle, lawnmower bracket and an oven heat adjustment knob. In some cases the student’s own examples turned out to be either too difficult or too simple to solve. However, for the most part the diversity of problems solved in the class has been a very good attribute in itself. A condensed illustration of the proposed design process can be seen in Figure 2. As an example, the bike
lock product is illustrated in the images starting with a close-up image of the fractured bike lock attachment in the first image. Since the project has a time constraint of about 14 days the students are given a relatively detailed and instructive design process proposal. The process is based on the reverse engineering design process proposed by Otto and Wood (1998).

![Diagram](image)

**Figure 2.** Illustration of the proposed design process used in the project including the main methods and tools utilized at various stages in the development.

In order to make a transition from the Operate (CDIO Syllabus 4.6.4 - System Improvement and Evolution (Crawley, 2007)) to the Conceive stage the first part of the assignment is to analyze the failure. The CDIO process is hence here interpreted as a cyclic and iterative process meaning that it may start with the Operate Stage preceding the Conceive Stage. For example when studying and testing failed existing consumer products in order to gather information for the Conceive Stage. If possible the students are encouraged to perform a breakage test and measure for instance the load necessary to break the component. This breakage test will further on provide input to the second part of the project where the student build a CAD model and perform an FE analysis in order to reproduce the stress condition leading to the failure. The students also perform an FMEA (Failure Modular Error Analysis) in order to find probably causes of failure.

During this process the students have normally asked several questions and learnt significantly about the component which provides a good basis for defining functions and requirements. The assignment continues with development of mechanical modelling and/or response modelling followed by optimization. The optimization results are used as input to the final design. Finally the new design is validated using FE analysis in order to verify improved performance.
PA 3 - Multi-objective optimization of an engine encapsulation component

This assignment targets learning objectives related to multidisciplinary problem solving and multi-objective optimization. The case is based on a real industrial problem concerning an engine encapsulation component with complex geometry and two layers of different materials.

![Diagram of design process](image)

**Figure 2. Illustration of the design process in the third assignment.**

The component should both act as a heat insulator and a noise absorber but still have a minimum mass. The students learn how to decompose a complex problem using simple analytical models and iteratively increase the modelling and optimization complexity from 1D to advanced 3D modelling in multi-physics software, see Figure 2.

The iterative nature of the assignment allows for active learning and self-assessment by, for instance, discussing and comparing the accuracy and sufficiency of different modelling approaches.

**COURSE EVALUATION RESULTS**

The course evaluation is carried using Chalmers’ standard method. A reference group of three to six students is appointed. The reference group and the teachers have three meetings. A first introductory meeting to learn to know each other and to discuss changes from previous course round and a second mid-course meeting to discuss the course so far and to implement possible minor improvements. The third meeting is the course evaluation meeting. At this meeting teachers, student reference group and program managements attend. The basis for the meeting is a web questionnaire and the impressions from students.
and teachers. Meeting notes including compiled questionnaire results are published and linked to the course description on the Chalmers course-web. The response rates for the questionnaires have varied from 58% to 70% (25-31 respondents).

In Figure 3, the student overall impression from the course questionnaires 2013-2016 are displayed. As can be seen, the first course round in 2013 was very well received by the students. The course was new and both student and teaching staff were enthusiastic and overlooked most issues related to novelty of the approach as well as planning difficulties. In 2014, the course had a new teaching staff and new administration which led to problems related to course administration and assessment.

What is your overall impression of the course?

Figure 3. Course evaluation - Overall impression

The course delivery did not meet the high expectations from the previous course round. In the following years the course has generally improved from a mean of 2.69 in 2014 to 3.74 and 3.68 in 2015 and 2016, respectively. Chalmers changed the standard method for course evaluation in 2014 leading to a discrepancy in terms of the questions in the course questionnaire except for the question regarding course overall impression. This limits the possibility to include year 2013 for detailed comparison.

A set of questions and corresponding results from the course evaluation from the years 2014-2016 are presented in Figure 4. Questions regarding course prerequisites, course structure, intended learning outcomes, assessments, workload and course administration are displayed above each sub-figure.

Figure 4(a) represents student’s feedback on the prerequisites to the course. The participating students are form different specializations in the mechanical engineering programme such as Product Development, Applied Mechanics and Automotive Engineering which brings variability and diversity in students’ prior knowledge. The course contents have been annually updated with improvements for lecturing material, workshops and supporting material. Figure 4(b) represents student’s opinion on course learning which consists of structure, teaching and course materials which shows an improvement through three years in terms of the mean satisfaction (3.1 to 3.6). This is gradually achieved by improving planning of the course; better alignment of lectures with learning outcomes; scheduling of lectures, workshops according to the need in assignments, removing certain topics from the course scope, etc. Consequently, the reflection on learning outcomes has been gradually improved although we have maintained it similar over four years, see Figure 4(c). Figure 4(d)
represents an improvement in opinion on assessment activities in the course although some comments were made to improve the evaluations, such as improvement in criteria for grading the assignments. There has been an inclination that the student’s grade is driven by the project assignment grade as they get higher grade in assignments compared to the final exam. Students pointed out that the mid-term exam was helpful to keep track on the progress of learning although they did not find the final exam to be challenging. The workload on the student’s side is comparative higher than other courses at Chalmers due to time intensive assignments in the course and other activities, which is also evident from Figure 4(e). Also, some students’ commented that it was too high work load and some said it was too low which seems to have been influenced by the motivation of students. To manage the excessive time demand, some of the workshops have been replaced by video lectures. The student impression of the course administration is displayed in Figure 4(f). The trend is somewhat typical for a new course with a continuous improvement to a well-established high level. The general lesson learned is to put a lot of effort in administrative issues and to be very clear in communication with the students both prior to and during the course.

a. Prerequisites: I had enough prior knowledge to be able to follow the course

b. Learning: The course structure (as divided into lectures, exercises, lab sessions, simulations etc.) is appropriate in order to reach the intended learning outcome of the course

c. Learning outcomes: The learning outcomes clearly describe what I was expected to learn in the course

d. Assessment: The assessment (including all compulsory elements, exams, assignments etc.) tested whether I had reached the intended learning outcomes of the course

e. Workload: The course workload as related to the number of credits was...
f. Course administration: The course administration (information during the course, course memo, course homepage etc.)
When the students were asked about what to preserve in the course, one of the most frequent comments was about keeping the project assignments, lectures, online videos and use of different CAE tools. Students found the project assignments challenging and rewarding and appreciated the group work, the cross-disciplines problems and knowledge sharing with peers from different background.

“The first assignment, it was very challenging and rewarding”

“Excellent! It feels good to work with students from different backgrounds, give me new vision of the engineering design.”

“The mix of theory and practice.”

When students were asked about what to change in the course, comments were about better scheduling coordination with workshops and lectures according to assignments, and students also asked for more mathematical exercise sessions. Although students appreciated the frequent communication with the teachers, they demanded more dedicated time for project supervision. There have also been comments regarding better formulation of the project assignments, which has been taken into consideration resulting in improved formulations.

“Very good intention, but contents should be more focused.”

“Overall the course was very interesting and is a course I recommend other to take. But because all the different subjects it gets a bit messy.”

“A good course that covers things that the bachelor program (M) missed out but would need more time to become really good. The course is way too compact in terms of the time span.”

Overall, students appreciated the course and found it intriguing and useful for future career. The course provided the aimed cross-disciplinary thinking and interesting design-built-test projects. Some of the comments from students are highlighted below:

“Really nice with all of the workshops and CAE tools.”
“Excellent course with a lot of material that was totally new to me.”

“This is by far the most useful course I have taken at Chalmers. When I signed up for the course I was not quite sure what to expect, but I am so glad that I did. This course has given me valuable knowledge about evaluating designs in so many different ways than I would have thought optimization applied to. Before taking this course I did not know exactly where optimization applied, but now I see how it can be used in ALL of my other coursework, for one thing or another.....The information that I learned from the EDO class will be used throughout my career as an engineer, this I am sure of.”

“Best course during my five years at Chalmers, got to use previous knowledge from several courses to solve “real” problems.”

“It was a really nice preparation for the "working life" after Chalmers due to the way of reporting and presenting.”

DISCUSSION

In general, the course has been perceived by the students as a valuable and important course even though there have been some apparent challenges as well. Some of the key aspects and factors we believe have been contributed to the successful attributes of the course are listed without order below.

- CDIO framework for course development including integrated-design-build-test experiences.
- Cross-disciplinary collaboration among three different departments with engaged and cooperative teaching staff.
- A dedicated funding program for new courses allocating resources for course development.
- Strong focus on fast design iterations and several loops within the design-build-test cycles.
- Emphasis on studying small subsystems or components in order to facilitate distinct system boundaries, requirements, constraints and real detail design.
- A combination of dedicated software workshops linked to theory lectures facilitates quick learning integration between theoretical concepts and software implementation in the project assignments.
- The workspaces and facilities developed within the ME program including for instance more than 40 student project rooms and a well-equipped and staffed prototype laboratory including a full mechanical workshop, CNC and 3D printing machines.
- Integration of a variety of communication and reporting techniques into the project assignments including A3-reports, oral presentations, technical briefing reports and simulated technical briefing meetings.

Some students consider the course as a capstone course based on the survey results. The students described how knowledge from most other mechanical engineering courses was needed in order to successfully excel in the course. This was not intended specifically from the beginning of the course development hence it is an interesting finding from the survey. With a similar motive and need as for this engineering design and optimization course, a new meeting platform called the National Optimization Arena in Sweden took form during 2015 to strengthen Swedish industries and academia. Chalmers University of Technology together
with Volvo Car Group were the initiators for this platform which aims to develop competence methods, tools and processes for optimization-driven development. A strong message voiced by the industrial partners is the importance for modern engineers to at least know the language of optimization even though not all of the students will continue their careers specifically in the field. The language of optimization is a generic and cross discipline bridge builder since the formulation of problems with objectives and variables follow a similar structure across engineering disciplines.

**CONCLUSION**

A new course integrating optimization with engineering design has been developed based on the CDIO framework including several design-build-test experiences. The intended learning outcomes (ILO) of the course have been outlined in close cooperation among faculty from three different departments and have become entrenched in the industry through discussions in program advisory boards, as well as several theses in cooperation with industry and in emerging research collaborations. The course was designed systematically using design matrices to maintain links between ILOs, teaching activities and assessments to ensure that every ILO is covered and assessed.

The course successfully combines theory in optimization problem formulation and analysis, optimization algorithms, and implementation in MATLAB into the mechanical design process including material selection and finite element analysis. The three integrated project assignments follow the iterative design-build-test cycles with focuses on topology optimization, reverse engineering and multi-objective optimization. Course design matrices verify that the project assignments are the backbone as they train and assess all ILOs, which is also obvious from students’ evaluations of the course in which they attribute much of the value of the course to the project assignments.

The interim and final outcome of the different design-implement experiences provide an opportunity for student self-assessment in terms of both the learning progress as well as results and modelling validity. The students strongly believed that the course prepared them well for work as professional engineers as well as for theses and research studies. Moreover, the course has had a strong impact on the students’ choice of master's thesis projects with the number of projects on optimization has increased from two or three to around 15 annually. The course has also tied faculty from the different departments together through the Optimization Arena and several joint multidisciplinary theses that involve optimization.
REFERENCES


BIOGRAPHICAL INFORMATION

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CDIO COURSE DEVELOPMENT FOR FACULTY IN RAW MATERIALS PROGRAMMES

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ABSTRACT

In Europe, the existing MSc programmes which are linked to the thematic Raw Material content often focus mainly on technical knowledge in itself, and students graduate as professionals who know how to solve pre-defined technical problems. Students in such programmes seldom practice entrepreneurial, communication and innovation skills at a level that is needed in working life. On the other hand, the CDIO Initiative has developed a framework for modernizing engineering education by introducing such skills and thinking into the technical programmes and courses. It is widely discussed in the CDIO community that one of the constraints in implementing CDIO is faculty staff professional development. CDIO standards 9 and 10 focus on the faculty development and competencies both in terms of pedagogic as well as learning methods to deal with personal and interpersonal skills, and product, process, and system building skills. In order to bring a change and implement CDIO into the Raw Materials programmes in Europe, a modular course for training in CDIO was developed and delivered for the faculty member in the Raw Materials sector. This paper accounts for the development of the faculty training course, and provides a unique perspective on the implementation of CDIO into raw materials related programmes capturing the different models of implementation from different universities’ programmes and courses. The various universities involved provide programmes and courses across the entire value chain of raw materials from mining and minerals processing to materials design, sustainability and recycling. This paper will serve as a reference for the educators to develop and implement CDIO education methods in specific disciplines as illustrated here in the field of raw materials related programmes.
KEYWORDS

CDIO Standards 9, 10; Faculty Development; Raw Materials; Course Development

INTRODUCTION

Modern engineers are engaged in all phases of the lifecycle of products, processes and systems who serve the need of the society. It is the responsibility of the engineering education to support their preparation for this. In Europe, the existing MSc programmes which are linked to the thematic Raw Materials (RM) content are often much focused on technical knowledge in itself, and students graduate as professionals who know how to solve pre-defined technical problems. Students in such programmes seldom practice entrepreneurial, communication and innovation skills at a level that is expected and needed in working life.

Today’s MSc graduates best suit large organisations where they are often destined for roles as technical specialists and experts. The large company can allow time for newly graduated engineers to learn on the job with senior colleagues, sometimes through trainee programs, etc. Neither small and medium-sized enterprises (SMEs) nor consultancies can seldom offer the same conditions for a slow start, and therefore the graduates need some additional skills in order to be more productive and independent from the start. Business and entrepreneurial schools exist at most universities, but these often gives a “standard offer” and seldom a tailor made content that is specific for Raw Materials sector.

The CDIO Initiative focuses on modernizing engineering education by introducing such skills and thinking into the technical programmes and courses. By implementing CDIO, students will encounter more real-world problems which are cross disciplinary and are set in a context which may include societal, legal, environmental and business aspects. Such problems are often characterized as complex and ill-defined, and there can be one or many solutions to evaluate in the light of the specific conditions. Members in 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).

The project CDIO (Edelbro et al., 2017) within EIT Raw Materials (Knowledge and Innovation Community - KIC) focuses on faculty development, active and experimental learning, and in future proposals most likely on design of student workspaces and laboratories. The project is aimed at bringing the change and contributing the higher education jobs and growth through enhancing the link between the knowledge triangle, i.e. the effective links between education and research to innovation (Allinson et al., 2012). This is associated with closer cooperation between education institutions, research organisations and businesses (Ranga & Etzkowitz, 2013). As a contribution to the development of the RM sector, the aim here is to strengthen engineering faculty competences related to innovation, entrepreneurship, business, etc. This objective is addressed by organising CDIO linked courses, communicative workshops, and inspirational guest lectures; by involving the “business and entrepreneurial” faculty in exploration, mining, mineral processing and metallurgy related issues; and also through curriculum and pilot cases developed together with industrial partners in the knowledge triangle.

Within this project there are several end customers and key beneficiaries such as RM industry, large traditional companies, entrepreneurs and SMEs, society, research institutes,
students and universities. Students in the MSc programmes will develop entrepreneurial, innovative, communicative and collaborative skills, as well as other professionally relevant competencies, within the technical area of RM. During the first year of this project, the faculty development as well as developing CDIO pilot cases for EIT RM is in focus. Engineering faculty members at the universities have the opportunity to increase their understanding of the professionally relevant competences that the students need to develop (CDIO Standard 9), as well as their own competence in matters related to designing programmes and courses to address these skills (CDIO Standard 10). Further, the university faculty get the possibility to communicate and learn from others through EIT partners, and throughout the large community of CDIO members.

This paper describes the development of, and the content for, a faculty training course used to introduce CDIO into raw materials related programmes and courses. The two-day CDIO course has been given on two occasions in the academic year 2016-2017, held at two locations: Chalmers University of Technology, Sweden, and University of Limerick, Ireland. The universities involved provide programmes and courses across the entire value chain of raw materials – from mining and minerals processing to materials design, sustainability and recycling. Implementation of CDIO into this wide range of programmes and courses will therefore provide a unique perspective.

LITERATURE REVIEW

The following section highlights the previous work and approaches which has been used to develop faculty training activities for CDIO and project-based learning (PBL).

The CDIO Initiative started in the year 2000 with the aim to reform engineering education for 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). Over the past 16 years, the initiative has grown from the four original founders (MIT, Chalmers, KTH and Linköping University) to a community of over 130 institutions. The framework for engineering education development has been progressed and extended through input from this dynamic community including most engineering disciplines. Within the initiative, discussions cover a range of topics related to the improvement of engineering programmes. This includes issues related to teaching product, process and system development, entrepreneurship, leadership, and emphasising personal, professional and interpersonal skills. The updated versions of the CDIO syllabus (Crawley et al., 2011) and CDIO Standards encapsulate the scope, rationale and generalised goals for developing programme and courses (see "CDIO Syllabus 2.0 | Worldwide CDIO Initiative", 2017; "CDIO Standard 2.1 | Worldwide CDIO Initiative", 2017).

Despite the fact that Standards 9 and 10 identify faculty competence as a key issue in engineering education development, there is a comparatively small number of articles in the CDIO literature concerning course development and deployment for training of faculty. Chuchalin et al. (2015) presented a modular course design for the development of CDIO Academy in Russia and argues that commitment of university, programme designer and teaching staffs plays an important role for successful implementation of CDIO. Experience has shown that peer learning, exchange of past experience, and collaboration between universities are some of the major driving factors to successfully implement CDIO (Loyer et al., 2011; Chuchalin et al., 2015; McCartan et al., 2016). Kozanitis et al. (2009) found
similarities in the CDIO teaching methods between five universities and five different subject and course structures, especially, they give examples on how CDIO is taught to their faculty. At KTH Royal Institute of Technology (KTH), Stockholm, Sweden, CDIO was the underpinning for a faculty development course taken since 2004 by a total of 700 faculty members. One of the requirements in this course was that participants should present a redesign of their own course, along with a reflective document providing the rationale for their educational choices. From Singapore Polytechnic, they give an example of a roadmap where the subject knowledge is divided into discipline knowledge and the 13 CDIO skills ("CDIO Syllabus 2.0 | Worldwide CDIO Initiative", 2017).

Although Edström & Kolmos (2014) have shown that CDIO and PBL (i.e. problem and project based learning) are quite different in scope, there is much to be learnt from examples of faculty training for PBL. Farmer (2004), shows that early faculty training and involvement is crucial for transition of curriculum change to adopt project based learning. The research, within a medical and health science education setting, showed that basic workshops on tutoring and developing PBL with mentoring from experts helped in competence development for the teaching staffs (Farmer, 2004). A similar mentoring approach for training faculty was shown to have a positive impact on faculty development (Smith & Ingersoll, 2004). Loyer & Maureira (2014) describe thoroughly, through proposing a model, how a course is transferred from one teacher to another with a mentoring approach, which also resulted in changes in the course to allow students to be more active. Malmqvist et al. (2008) highlight the need for, but also the lack of, organized forward looking competence programmes at a few universities. They point out several areas where there is a need for faculty development in modern universities. Some of the competences identified are particularly relevant to apply in engineering courses in the raw materials sector, e.g. using project based teaching methods, and contributing to the universities strategic goals.

From literature, it can be seen that the CDIO is a community-driven initiative and learning from shared experience and mentoring are important aspects. In the raw material sector, the university education today is overall traditional compared to other fields such as mechanical engineering and the examples of CDIO implementation in RM related programmes/courses are scares. This paper describes the important segment of making the RM sector’s education modern. In this paper, the development of the CDIO course is described including the formulation of learning objectives, the design of a course framework aligned with these learning objectives, development of course content relevant for implementing CDIO in raw materials programmes, and finally feedback from the participants. This is followed by the discussion on the relevance of such CDIO courses into raw materials and future work to be carried forward.

CDIO FACULTY DEVELOPMENT COURSE LEARNING OBJECTIVE

The implementation started with an initial meeting with all stakeholders, including the participating university representatives and company representatives. Guided by the EIT RM project scope and feedback from CDIO experts, the foundation was laid through the development of the learning objective for the course, see Table 1. The learning objectives basically covered three aspects; the rationale for using CDIO (L1), the application of CDIO in curriculum development (L2) and the application of CDIO in course development (L3).
CDIO FACULTY DEVELOPMENT COURSE FRAMEWORK

The implementation of CDIO in curriculum and course design requires supporting the faculty members to understand the concepts and methodologies of CDIO. Taking a cue from different faculty training activities carried out across the CDIO community, the CDIO faculty development course was organised in a modular framework. Using the learning objectives as a basis for course design, the CDIO faculty development course was organised in 3 modules as shown in Table 2. Each module is mapped to the learning objectives and the content is further mapped to the modules. The course is typically delivered using seminar presentations, case study presentations, workshops, active discussions, and laboratory & workspace tours.

Table 1. List of Learning Objectives for CDIO Faculty Development Course

| L1   | Explain the rationale of the CDIO approach to engineering education. |
| L2   | Apply the CDIO methodology to curriculum development, including     |
| a.   | Formulating learning outcomes on the program level                  |
| b.   | Devising a curriculum to integrate disciplinary fundamentals with personal and professional skills and attitudes, in particular business and entrepreneurship skills |
| c.   | Giving examples of strategies to enable and drive program-driven course development |
| L3   | Apply the CDIO methodology to course development, including         |
| a.   | Formulating learning outcomes on the course level                   |
| b.   | Developing appropriate learning activities for discipline-led learning and for problem based/project organized learning |
| c.   | Developing appropriate assessment methods aligned with the intended learning outcomes |
| d.   | Suggesting ways to address business and entrepreneurship skills on the course level |

Table 2. Modular Design of the CDIO Faculty Development Course and Learning Objective Alignment

<table>
<thead>
<tr>
<th>Module 1 (M1)</th>
<th>Train and create awareness of CDIO initiative and how to implement CDIO in raw material related programme and course development.</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>CDIO Introduction, History</td>
</tr>
<tr>
<td>b.</td>
<td>CDIO Syllabus and Standards</td>
</tr>
<tr>
<td>c.</td>
<td>Methods for curriculum design</td>
</tr>
<tr>
<td>d.</td>
<td>Methods for course design</td>
</tr>
<tr>
<td>Module 2 (M2)</td>
<td>Show examples and case studies to give ideas and inspiration to the practitioner to implement CDIO both at programme level and course level.</td>
</tr>
<tr>
<td>a.</td>
<td>Case study on curriculum design</td>
</tr>
<tr>
<td>b.</td>
<td>Case study on course design</td>
</tr>
<tr>
<td>c.</td>
<td>Case study on involvement of Business and Entrepreneurship in Engineering</td>
</tr>
<tr>
<td>Module 3 (M3)</td>
<td>Developing CDIO based curriculum, courses and projects for the specific programmes and courses related to the field of raw materials including mining and metallurgy aspects with industrial involvement.</td>
</tr>
<tr>
<td>a.</td>
<td>Workshop on curriculum design</td>
</tr>
<tr>
<td>b.</td>
<td>Workshop on course design</td>
</tr>
</tbody>
</table>
CDIO FACULTY DEVELOPMENT COURSE CONTENT AND IMPLEMENTATION

The modular design of the course provides flexibility for the customization of the course content for practical reasons. There are many practical challenges in building and organising such courses for universities, for instance, the location of the course delivery since some participants need to travel, availability of experienced facilitators, scheduling and duration of the course, and motivation from participants for attending the course. The pilot CDIO faculty development course was hosted at two locations. The content of each course was customised, as described in the following sections.

CDIO Faculty Development Course, Chalmers

The first two-day CDIO Faculty Development course was organised at Chalmers University of Technology on 25th-26th October, 2016. A summary of the course content is presented in Table 3.

Table 3. Course Content for CDIO Faculty Development Course, Chalmers

<table>
<thead>
<tr>
<th>Day 1</th>
<th>Topic</th>
<th>Module</th>
<th>University</th>
<th>Delivery Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Introduction to CDIO</td>
<td>M1: a, b</td>
<td>Chalmers</td>
<td>Seminar</td>
</tr>
<tr>
<td></td>
<td>Program Development</td>
<td>M1: c</td>
<td>Chalmers</td>
<td>Seminar</td>
</tr>
<tr>
<td></td>
<td>Course Development</td>
<td>M1: b, d</td>
<td>KTH</td>
<td>Seminar</td>
</tr>
<tr>
<td></td>
<td>Industrial Engagement on Teaching</td>
<td>M2: a</td>
<td>Limerick</td>
<td>Seminar</td>
</tr>
<tr>
<td></td>
<td>CDIO Case Study - Program Development</td>
<td>M2: a</td>
<td>Chalmers</td>
<td>Case Study, Active Discussion</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Day 2</th>
<th>Topic</th>
<th>Module</th>
<th>University</th>
<th>Delivery Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CDIO Tools for Teaching Material - Case Study on Product Development Course</td>
<td>M2: b</td>
<td>Chalmers</td>
<td>Case Study, Active Discussion</td>
</tr>
<tr>
<td></td>
<td>CDIO - Case Study on Course Development</td>
<td>M2: b</td>
<td>Limerick</td>
<td>Case Study</td>
</tr>
<tr>
<td></td>
<td>Design Build - Simulation Based Learning</td>
<td>M2: b</td>
<td>Chalmers</td>
<td>Case Study, Laboratory &amp; workspace tour</td>
</tr>
<tr>
<td></td>
<td>CDIO- Business and Entrepreneurship</td>
<td>M2: c</td>
<td>Limerick</td>
<td>Case Study</td>
</tr>
</tbody>
</table>

Sessions on the topics were facilitated by experienced faculty members, programme developers and CDIO experts from three universities: Chalmers University of Technology, Sweden; KTH Royal Institute of Technology, Sweden; and University of Limerick, Ireland. The case studies presented were from mechanical engineering programmes, business and entrepreneurship programme, computer science and IT programmes and a naval architecture programme.

Participants and their Feedback

In total, 31 participants from 9 universities participated in the course and feedbacks was collected through a survey after the course. Overall, the participants were highly satisfied with the course, rating it 5.13 on a scale from 1 to 6 (15 responses). The participants found the CDIO examples and experiences to be valuable for learning about CDIO. Other notable positive highlights from the course experience were: the diversity in examples of project-based learning (design-implement experiences), the cross disciplinary audience, and discussions stemming from the presentation of case studies. Feedback also demonstrated a
need to reduce the time for presentation, and include more of workshop/hands-on experiences and group activities. The main learning outcomes, or take away messages for the participants were the structured and systematic methods to change programmes and courses; and new strategies to implement the same. They also appreciated that the course gave the rationale behind CDIO implementation, while real cases and scenarios gave ideas and inspiration to change their own programmes and courses.

**CDIO Faculty Development Course, Limerick**

The second two-day CDIO Faculty Development course was organised at University of Limerick, Ireland on 10th - 11th January, 2017. Similar to the first event, topics were delivered by CDIO leaders from Chalmers University of Technology, Sweden; KTH Royal Institute of Technology, Sweden; and University of Limerick, Ireland. Having examined the feedback, detailed in the previous section, the Faculty Development Course in UL focused on delivering “more hands on experience and group activities”, while ensuring that participants were still grounded and aware of the CDIO fundamental principles and standards. The course content summary is presented in Table 4.

**Table 4. Course Content for CDIO Faculty Development Course, Limerick**

<table>
<thead>
<tr>
<th>Day 1</th>
<th>Topic</th>
<th>Module</th>
<th>University</th>
<th>Delivery Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Introduction to CDIO</td>
<td>M1:a, b</td>
<td>Chalmers</td>
<td>Seminar</td>
</tr>
<tr>
<td></td>
<td>Program Development</td>
<td>M1:c</td>
<td>Chalmers</td>
<td>Seminar</td>
</tr>
<tr>
<td></td>
<td>Course Development</td>
<td>M1:b, d</td>
<td>KTH</td>
<td>Seminar</td>
</tr>
<tr>
<td></td>
<td>Instructional Method and Student</td>
<td>M2:a, b</td>
<td>Limerick</td>
<td>Seminar</td>
</tr>
<tr>
<td></td>
<td>Learning</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CDIO Self-Assessment Standards &amp;</td>
<td>M1:b</td>
<td>Chalmers</td>
<td>Active Discussion/Round table</td>
</tr>
<tr>
<td></td>
<td>Rubric</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Methods to Improve Student Learning</td>
<td>M2:a, b</td>
<td>KTH</td>
<td>Active Discussion</td>
</tr>
<tr>
<td>Day 2</td>
<td>CDIO Tools – Put learning back into</td>
<td>M2:a, b</td>
<td>KTH</td>
<td>Case Study, Active Discussion</td>
</tr>
<tr>
<td></td>
<td>Project Based Learning</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Enabling and Facilitating Entrepreneurial skills</td>
<td>M2:c</td>
<td>Limerick</td>
<td>Seminar</td>
</tr>
<tr>
<td></td>
<td>Design Build Compete</td>
<td>M2:b</td>
<td>Chalmers</td>
<td>Active Discussion</td>
</tr>
</tbody>
</table>

Participants and their Feedback

In total, 28 participants from 4 universities participated in the course and once again feedback from the participants was collected through a survey conducted after the course. Overall, the participants were highly satisfied with the course, rating it 5.63 on a scale from 1 to 6 (11 responses). When asked if the programme content was relevant and applicable it rated 5.7 on a scale from 1 to 6.

Feedback from the programme illustrated that participants welcomed the time, space and structure to focus on their own programmes and to work together to self-assess their programmes within the CDIO framework. The need to fundamentally tie programme material to learning objectives and to make students aware of these learning objectives was also crystallised during the development programme. A common theme from participant’s feedback was the valuable discussion on how student project work is/could be assessed, how feedback is/could/should be provided and at which stage during a project feedback is
most beneficial to the students. Some feedback suggested that because the topics had generated much discussion, that more time in the programme could have been allocated to round table or open floor Q&A to learn from others experiences.

Participants were asked, through survey, which items from the development programme they would apply in their programme/courses, the overwhelming response was different techniques of feedback in courses and projects. All participants of the survey indicated that they intend to examine feedback system within their programme/module post discussions arising from the faculty development programme. How feedback could be altered to be more meaningful to the students, more formative for the students, but also how it could be given by student-to-student and facilitate the lecturer to focus on other aspects of the module.

Participants were also asked what steps they need to make desired change within their programme, responses here varied from establishing working groups within department, to informal communication with colleagues, to support from technical staff and faculty. However the common theme indicated by these responses to help make change within programmes then open communication channels between academics within universities is a fundamental requirement.

DISCUSSION

A two-day programme including fully aligned learning objectives for a faculty course has been created and lectured twice. However, there are several more, as important, outcomes from this, and they will be discussed here.

Through these courses, an awareness and opportunity was created for the faculty members teaching in raw materials MSc education to think about the underlying benefits of implementing CDIO within their course and programme. Also, this kind of course shows intensive examples from successful implementation of CDIO, which can motivate the participant in taking the next step to change. In order to continue working with such change, commitment is required from individual universities and other stakeholders to continually develop these aspects of their programmes and course.

The CDIO framework, as expressed in the syllabus and standards, gives general guidelines to review and develop engineering education in terms of product, processes, and systems development. The fact that the raw materials sector, at least within the secondary resources (substitution and recycling), to a large extent also deals with such terms, it implies that adoption of CDIO to the Raw materials education will be correspondingly possible. At the same time it will require some alteration in adoption, especially in the primary resource sector (exploration, mining, etc.) and at this point of time it cannot be fully estimated to what extent it can be adopted. The process of translation and transformation will also produce new knowledge and ways of implementation, which is potentially, a contribution back to the CDIO community.

There are many resources and examples available through the CDIO community to show application of design-implement projects for product-based applications, but comparatively fewer examples relevant to process oriented applications. This poses a challenge for raw materials related courses to develop effective project-based learning experiences within process oriented courses. Introducing the CDIO approach to raw materials programs poses a wide scope for development of unique pilot case studies, laboratory and workshop.
development, and collaborative teamwork exercises. Raw materials related industrial and technological involvement together with the CDIO syllabus would play an important role in the development of such exercises.

The feedback from the two courses’ show that the participants appreciated the experience within the CDIO community, and felt that the examples showing successful implementations were highly motivating. This finding is consistent with other reports in the literature (Farmer, 2004; Loyer et al., 2011; Chuchalin et al., 2015; McCartan et al., 2016). However, an additional observation made here is that the participants appreciated the dedicated time and session for working with their own programmes and courses. The utility of such courses will increase when the participants are underway making improvements in their own programmes and courses. Conducting the course in workshop format, to include time and support for participants’ own projects, will likely further develop this particular aspect. The documented results can then also serve to ensure that the learning outcomes of the course are met.

The participants from RM universities expressed the opinion that the CDIO implementation is a long-term process, especially at programme level. There are constraints from different universities’ strategies and systems when it comes to changing programmes and courses, which is also highlighted from research by Malmqvist et al. (2008). There is a need for a continuous training of teaching faculty within the CDIO initiative to get a better consensus on developing programme and courses in RM. On a higher level impact, the CDIO initiative fits very well on meeting the goals and vision of EIT Knowledge and Innovation Community (KIC) and can substantially be linked to a long term growth in terms of competence development. Further, this will lay foundation for long term innovation within education system of RM by building sustainable relationship between industry and education; by involving students with real time project experience from industry; and helping in equipping engineers with ad-on skills of business, communication, critical thinking, and entrepreneurship.

**Future Work**

The developed faculty course is a two-day course for introducing participants to CDIO. To get more faculty involved; and to enable sustainable programme and course development at different participating universities, a longer period with CDIO is warranted. The faculty development course will be extended to a workshop format where the participant can bring their own programme and courses and can apply CDIO principles under the mentorship of CDIO leaders. This is currently included in module 3 (M3) of the course, see Table 2. With the development of cases and experience from the RM sector, new case studies of direct relevance will be featured in the course. The course/workshop promotion is also an important aspect when it comes to increasing the number of interested participants, to leverage the impact of this activity.

**CONCLUSION**

Chalmers University of Technology, Sweden and University of Limerick, Ireland jointly developed and organised two successful faculty development course given at the two respective locations. The course was designed to provide support to the various universities involved in providing programmes, across the entire value chain of raw materials. The modular CDIO faculty development course provides the benefit of being flexible in terms of organisation and delivery. This serves as a sustainable course with built-in ability to expand and customize while ensuring the same learning outcomes. This paper can be used as a
reference for further development and implementation of the CDIO initiative in other disciplines. In order to drive a continuous development and creation of sustainable education in RM 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 RM.

REFERENCES


**BIOGRAPHICAL INFORMATION**

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EXPERTS IN TEAMWORK -
A LARGE SCALE COURSE FOR INTERDISCIPLINARY LEARNING
AND COLLABORATION

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ABSTRACT

Experts in Teamwork is a mandatory course at the Norwegian University of Science and technology (NTNU) for all master students, regardless of program, where the students work in interdisciplinary teams on real world projects, with detailed and explicit intended learning outcomes for personal and interpersonal skills using active and experiential learning approaches. In this study, we used a mixed method research approach with a quantitative analysis that capitalize on the course evaluation data from the last 10 years and a textual qualitative analysis of the project descriptions of some of EiT villages. Based on the empirical data, we discuss the extent to which the students perceive EiT as a valuable preparation for their work life, and what factors are important for the development and success of the EiT course in the light of the relevant scientific literature.

KEYWORDS

Interdisciplinary learning, project-based learning, cooperative learning, generic and transferable skills, course development, CDIO Standards: 2, 7 and 8.

INTRODUCTION

Engineering education has been criticized for neglecting to provide students with opportunities to develop skills that are crucial to practicing engineers (Crawley, Malmqvist, Östlund, Brodeur, & Edström, 2014). These skills include, for example, communication, team-working, project management, and problem-solving (Berggren et al., 2003; Galloway, 2007; National Academy of Engineering, 2005). Engineering education aims to prepare students for their later work life, where they will work on questions that are unknown to us at the moment. Therefore, it is not enough to only equip students with the necessary discipline specific knowledge and skills, we must also teach them how to learn and how to collaborate (Kenny et al., 1998).
In 2015, *Nature* ran a special issue on interdisciplinary research (Nature, 2015), highlighting the importance of collaboration across disciplinary boundaries, and the UN summarized the great challenges that we face as a global society in their “17 goals to transform our world” (www.un.org/sustainabledevelopment/). All of these challenges require expertise from many different disciplines in order to fully understand and address them. Communicating and collaborating in interdisciplinary settings are key skills we need students to train and master. Interdisciplinary collaboration means that the contributors work together by integrating their knowledge and methods, and work is carried out jointly to achieve a shared goal by combining expertise from different disciplines (Choi & Pak, 2006). This is in strong contrast to multidisciplinary collaborations, where the work is carried out independently, or sequentially, from each discipline-specific perspective, which greatly limits the possibility to integrate perspectives and utilize different disciplinary points of view (Viseu, 2015).

Interventions to improve engineering education, such as the implementation of active and collaborative learning, have mainly targeted first- and second year courses (Heitmann, 2005). Little work has been done to improve teaching and learning in later courses. It is, however, important to keep students interested throughout their education and help them to advance beyond simply memorizing knowledge (Balakrishnan, Lal, & Flattau, 2008).

During the 1990s several initiatives were undertaken by the Norwegian Ministry of Education with the aim of improving the quality of higher education. As a result, NTNU reframed itself as an innovative university concerning collaboration and interaction across disciplinary boundaries (Sortland & Erichsen, 2006). Continued work, including stakeholder analysis, resulted in calls for educational development to equip students with the necessary skills and tools to work across disciplinary boundaries.

“The teaching of engineers shall produce candidates who possess fundamental knowledge of natural science, technology and society in general, who have acquired social abilities, are trained in team work and coaching and motivating of co-workers, are good in verbal and written communication, are able to use their competence to foster creativity and solve complicated and multifaceted problems, and can adjust to changing demands. Students have to be trained in teamwork, adjustment to changes in their professions and society, and be efficient in professional work.” (NTH utredning, 1993)

Conventional lectures should be replaced by project work and self study in teams working on practical problems, to illustrate how the theory learnt on the bachelor level could be applied. A fundamental idea behind the desired change, was to prepare the students for life long learning, rather than considering the graduates as final products (Sortland, 2006). A consequence of this work was a major revision of the Master of Science program at NTNU during the 1990s (NTH utredning, 1993). The course Experts in Teamwork (EiT) was established in 2001 as a mandatory course at the master level, requiring a radical change of teaching, from lecturing and instructing to facilitating, i.e. to facilitate the development of abilities in cooperation, reasoning and decision-making in teams. The change was hard for many teachers, and it took several years of planning and testing to implement the desired changes (Sortland, 2001).

In this case study, we investigate the development and current status of the EiT course through the analysis of quantitative and qualitative data from 2007-2016. Through focusing on students interdisciplinary collaboration and their self-evaluated gain in collaboration skills, we address the following two research questions:

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*Proceedings of the 13th International CDIO Conference, University of Calgary, Calgary, Canada, June 18-22, 2017.*
1) To what extent do students perceive EiT as a valuable preparation for their work life?
2) What factors are important for the development and success of the EiT course?

Based on the empirical data and through discussion of relevant findings in the scientific literature, we provide some general pointers on how to promote interdisciplinary collaborations amongst students and important consideration in the continuous development of large scale courses.

THE EXPERTS IN TEAMWORK COURSE

Since the original education development project, the EiT course has been continuously improved and developed further. Today, it is a compulsory 7.5 ECTS course for all master degree students at NTNU. With about 2000 students, EiT is NTNU's largest course, and engineering students collaborate on real world problems with students from other study programs, including non-engineering programs.

The central EiT staff organizes the course in cooperation with the faculties, and has academic responsibility for the experiential learning method supporting the development of the students' cooperative skills. The EiT staff also prepares learning materials and methods, and coordinates censorship, and is responsible for the hiring, training and supervision of all the village leaders and learning assistants. Finally, it is the EiT staff that is responsible for the continuous development of the EiT course.

The EiT course is organized in 70-90 classes which are called villages, with up to 30 students each. There are two types of villages: intensive villages takes place every weekday in a three-week period starting at the beginning of January, while semester-based villages takes place every Wednesday throughout the spring semester. Among the villages, 4 of 5 groups are Norwegian speaking, and 1 in 5 are international villages with English as a course language. The different villages are organized by the seven different faculties at NTNU and each faculty needs to offer approximately as many places as they have students participating in EiT.

Each village has a broad overall academic theme related to societal issues or challenges from working life. This theme forms the basis for the student team’s project work. The village may have external partners that represent the theme, and who may be advisers or recipients of the students’ work. The village themes are presented on the EIT website in the fall semester, and the desired combination of subjects in the villages is specified as a guide to help students choose a village. Students are allocated to the villages on the basis of their preferences, the village’s need for competence in various disciplines, and the number of places in the village. The presentation of the village teams aims to describe possible projects and create interest for the village in order to recruit students from a wide variety of disciplines. In recent years, about 90% have been granted a place in the village they had chosen as first or second priority. Students tend to choose villages within their own faculty resulting in less interdisciplinaryity than desired.

The overall learning outcomes and methods are the same for all villages. Each village is run by a member of the academic staff, and two learning assistants, who function as facilitators for the groups. The intended learning outcomes for the EiT course include that after the course the student can:
• reflect on how their teamwork is influenced by their own behaviour patterns and attitudes, as well as those of others.
• take initiatives (actions) that encourage cooperation, and they can change their patterns of interaction if necessary.
• provide feedback to others in the team in constructive ways, and reflect on feedback from the team.
• have extended their perspective on their own specialized knowledge in their encounter with skills from other disciplines. They can communicate and apply skills they have developed in their own field in collaboration with students from other disciplines.

(A full list of the intended learning outcomes for the course can be found here: https://innsida.ntnu.no/wiki/-/wiki/English/Experts+in+Teamwork) These learning outcomes are directly coupled to some of the CDIO standards such as detailed learning outcomes for personal and interpersonal skills (Standard 2), integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal and interpersonal skills (Standard 7), and teaching and learning activities based on active and experiential learning methods (Standard 8).

The underlying educational approach is based on experience based learning and reflections (Andresen, Boud, & Cohen, 1995). Instead of learning about cooperation, using a knowledge based learning method; students in EiT acquire cooperative skills by experiencing and reflecting on teamwork in practice. The experiences of the individual and the group in the interdisciplinary team form the basis for reflection, evaluation, change and learning (Sortland (ed.), 2016). EiT use David A. Kolb’s pedagogical model to describe the learning process (Kolb, 1984): (i) concrete experience – the student has to be willing to take themselves and their experiences as a starting point for reflection with the others in the team; (ii) Reflection on experience – team members verbalize thoughts, emotions and actions related to a common situation. One way in which this is supported in EiT is that students write personal reflections in their Book of Reflections during the day and team reflections at the end of every village day; (iii) Abstract conceptualization – the ability to identify and describe the team’s patterns of behavior, attitudes and development adequately with support from relevant academic literature; (iv) Active experimentation – the ability and willingness to try out new behaviors to improve the dynamics in the team. The team must also consider and evaluate their new behaviors in retrospect (Sortland, 2016).

To promote experienced based learning, students in each village work in interdisciplinary project teams of 5-6 students on a self-defined topic coupled to the village theme based on the expertise each group member contributes. All projects that the students work with should be coupled to current challenges in society and the final project report and presentation should show how these problems were addressed through the combined expertise of the students. In addition to the project report, the students are required to analyse their teamwork and, based on their understanding, reflect on how they communicate, plan, make decisions, solve tasks, handle disagreements and relate to academic, social and personal differences. It is through these reflections that student teams should become aware of their team dynamics and learn how to collaborate in interdisciplinary teams. Team members perform reflection activities together, stimulated by facilitation, exercises in teamwork and feedback. To stimulate reflection in the student teams, facilitation is used as a pedagogical tool. The practice of facilitation in EiT differs from facilitation as described in organizational psychology and group leadership. The learning assistants, who function as facilitators, are older students who have received training in observing team behaviour and asking open questions. The input from the facilitators support the students’ reflection about the team’s
dynamics and their individual contribution to the whole. The team’s experiences are gathered in a separate process report at the end of the semester.

The final assessment in the EiT course is based 50% on the project report and 50% on the process report. Each group is given a group grade and there are no individual grades given to the students, but all students are required to perform and deliver a perspective evaluation at the end of the course that focuses on their individual development. More information on EIT including the course description is available at: www.ntnu.edu/eit.

RESEARCH APPROACH

As the purpose of the study is to investigate students’ perceived value of the EiT course and factors that are important for the development and success of project villages in the course, a mixed method research approach was used. Johanson and Onwuegbuzie (2004) defined mixed methods research as “the class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single study”. This approach combines the strength of both quantitative and qualitative research, allows for triangulation between different data sources to increase trustworthiness, provides a more comprehensive picture of the studied phenomena, helps to better explain the findings, and is particularly useful in the development and testing of hypothesis and instruments (Doyle, Brady, & Byrne, 2009; Ivankova, 2006).

Case studies are characterized as a bounded system – such as an individual, a group, a course or a program – chosen because it is “unique, experimental or highly successful” (Shaw, 1978). In the present study, the EiT course was chosen as an interesting case, as it is unique in its size, provides students with important skills for the 21st century, and has successfully run at NTNU for many years. The quantitative data in this study was collected through a course evaluation instrument based on Likert scale questions between 2007 and 2016, with response rates above 80% in all years. We focus particularly on the evaluation data from 2016, which include answers from 1731 students from all 73 project villages (response rate 86.3%). The quantitative data was analysed using descriptive statistics to highlight general aspects of the EiT course, while Pearson’s correlation was used to investigate the relationship between different measured variables (Borrego, Douglas, & Amelink, 2009). All quantitative data was anonymized and analysed using SPSS.

In order to further explore some of the quantitative findings in more detail, the village descriptions were analysed using a qualitative research approach. For the first step of the analysis, all descriptions were analysed using open coding, and in a second step a comparative approach was taken to better understand differences and similarities between the descriptions. All village descriptions were read and coded by two researchers to minimize investigator bias (Krefting, 1991).

RESULTS AND DISCUSSION

Student perceived relevance for work life

In first part of this study, the students’ perceived relevance of the EiT experience for later work life is examined. One of main goals of EiT is to better prepare students for later work life and help them to acquire the necessary skills to work in diverse teams later on. In one part of
the course evaluation surveys, students are asked to evaluate their own experience in the EiT course and how well it will help them in the future. A summary of the statements that students evaluate on a scale from 1 to 5 is given in Table 1 together with the overall mean value for the entire EiT course. In addition, the scores for the three villages with the highest overall student satisfaction and the three lowest are given in the table.

Table 1. Students’ perceived relevance of EiT for work life

<table>
<thead>
<tr>
<th>Statement</th>
<th>Mean for all EiT villages</th>
<th>Project 1</th>
<th>Project 2</th>
<th>Project 3</th>
<th>Project 4</th>
<th>Project 5</th>
<th>Project 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall satisfaction</td>
<td></td>
<td>3.74</td>
<td>4.55</td>
<td>4.24</td>
<td>4.2</td>
<td>3.06</td>
<td>3.96</td>
</tr>
<tr>
<td>In the future, I will benefit from experience I gained in my group</td>
<td></td>
<td>3.78</td>
<td>3.9</td>
<td>4.24</td>
<td>4.4</td>
<td>3.18</td>
<td>2.71</td>
</tr>
<tr>
<td>I see more value in this type of work now than before we started</td>
<td></td>
<td>3.51</td>
<td>3.95</td>
<td>4</td>
<td>4.47</td>
<td>2.82</td>
<td>2.47</td>
</tr>
<tr>
<td>Working in the group has given me new thoughts and ideas about how to work together in the future</td>
<td></td>
<td>3.68</td>
<td>4</td>
<td>4.12</td>
<td>4.4</td>
<td>3.24</td>
<td>2.76</td>
</tr>
<tr>
<td>Experience from the group has increased my confidence in the importance of good teamwork</td>
<td></td>
<td>3.78</td>
<td>4.4</td>
<td>4.04</td>
<td>4.37</td>
<td>3.76</td>
<td>2.65</td>
</tr>
</tbody>
</table>

In general, the students perceive their EiT experience to be relevant for later work life and feel that it prepares them for future tasks. The students also acknowledge the importance of the EiT experience and think that it has stimulated new thoughts and ideas that will be valuable when working in teams in the future. Furthermore, it is important to note that there is a strong Pearson’s correlation between overall student satisfaction and the four statements in this part of the course evaluation form, with correlation factors of 0.73, 0.75, 0.65, and 0.7, respectively.

While student satisfaction does not provide a comprehensive measure of course quality, we argue that it offers valuable information and a starting point for more in-depth investigation. In an extensive and careful meta-analysis of Student evaluation of teaching Uttl et al. (2016) found no correlation between student satisfaction and student learning. Student satisfaction do, however, correlate well with creating engagement and motivation for future work and studies. Students with a positive experience from working within interdisciplinary teams are arguably more likely to accept and function well in future teamwork (Tucker & Abbasi, 2016). The strong correlation between student satisfaction and the four other statements implies a connection that it is worth to explore further.

Another limitation of the current study is that it is built merely on students’ self evaluations. In the future, it is desirable to perform a more thorough follow-up study that investigates students’ reflections upon their EiT experience after they leave university and are active in the work-place. Also, the perceived value of EiT for companies and work places that hire
students need to be investigated. These are important areas for further research, but in this current study we focus on the available data from 2007 to 2016.

**Continuous development of the course**

Students have been asked about their overall satisfaction with the EiT course since 2007, which makes it possible to look at the progress over time. While student satisfaction does not necessarily correlate with learning, as noted above, there is valuable information to extract from students’ overall perception of a course. Figure 1 shows a summary of the satisfaction data between 2007 and 2016. There is a clear increase in students’ overall satisfaction from year to year until 2010. After 2010, the rate of change diminishes, but the trend of increasing satisfaction remains and the numbers stabilize at a high levels, with over 90% of the students somewhat satisfied, satisfied, or very satisfied. In the 2016 EiT course, only 7.1% of the students were dissatisfied or very dissatisfied.

![Figure 1. Students’ overall satisfaction with the EiT course 2007-2016](image)

Figure 1 illustrates the importance of continuous and sustained development of a course. In 2007 still as many as 31.5% of the students reported dissatisfaction to some degree, a number that has since dropped from year to year due to diligent work on improving both form and contents of the course. Instructional design for a course that deviates from conventional teaching-learning activities need to be evaluated and developed over a period of time. It is necessary to accept that improvements are made stepwise from year to year, requiring sustained effort from continuous development. This has been helped by a continuity in staff. Also, it has taken some time to establish a climate, and a culture, where students (and teachers) not only accept, but buy into the collaborative format of the EiT course. One aspect that we will examine closer in future work is how the students’ attitudes to teamwork changes during the EiT course.

**Project success factors**

When taking a closer look at the students’ overall satisfaction data from 2016, it becomes apparent that there are only small differences in mean satisfaction both between the semester-long and the intensive variants of the EiT course, as well as between students’
disciplines of study. By contrast, there is considerable variation in student satisfaction on the project village level (2.79-4.55 on a scale from 1-5). The top three villages have student satisfaction scores of 4.55, 4.24, and 4.20, whereas the bottom three villages have scores of 2.96, 3.00, and 3.06.

Taking a closer look at these villages and their boundary parameters reveals that the top three villages are more diverse in their student population than the bottom three. Table 2 shows the number of different faculties that students come from in the six villages, as well as the interdisciplinarity index ($i$:index) for each village. The $i$:index is a measure of the variation within each village (0-1), where a high index means higher variation. It is calculated through equation 1 based on a harmonic series, where each additional student from the same faculty adds less and less to the index. The $i$:index is normalized to the number of students and the maximum possible diversity.

The villages with the three highest students’ overall satisfaction scores have students from five or six different faculties out of seven faculties at NTNU. The high diversity in the students’ disciplinary backgrounds is also obvious from the $i$:index for these villages that ranges between 0.88 and 0.73. The bottom three villages on the other hand have students from only four or even two different faculties, which greatly limits the disciplinary diversity of the students, with $i$:indices between 0.58 and 0.48. The correlation factor between students’ overall satisfaction and the $i$:index for these villages is 0.95.

Table 2. Comparison of the top and bottom three villages of EiT in 2016

<table>
<thead>
<tr>
<th>Project number</th>
<th>Students’ overall satisfaction</th>
<th>Number of different faculties</th>
<th>Normalized interdisciplinarity Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project 1</td>
<td>4.55</td>
<td>6</td>
<td>0.88</td>
</tr>
<tr>
<td>Project 2</td>
<td>4.24</td>
<td>6</td>
<td>0.80</td>
</tr>
<tr>
<td>Project 3</td>
<td>4.20</td>
<td>5</td>
<td>0.73</td>
</tr>
<tr>
<td>Project 4</td>
<td>3.06</td>
<td>2</td>
<td>0.48</td>
</tr>
<tr>
<td>Project 5</td>
<td>3.00</td>
<td>4</td>
<td>0.58</td>
</tr>
<tr>
<td>Project 6</td>
<td>2.96</td>
<td>4</td>
<td>0.58</td>
</tr>
</tbody>
</table>

\[
i:\text{index} = \frac{\sum_{n=1}^{\# \text{students faculty } 1} 1 + \sum_{n=1}^{\# \text{students faculty } 2} 1 + \sum_{n=1}^{\# \text{students faculty } 3} 1}{\text{Maximum possible diversity}}
\]  

(1)

It is not unreasonable to assume that the variations in student satisfaction we observe between villages are influenced by differences in cultures among teachers and research cultures in the different departments and faculties. We can observe that the same village leaders consistently host satisfied teams. The framework of describing collaborations in terms of multi-, inter-, or transdisciplinary work can be a starting point for a closer study. Understanding of what collaboration entails varies between different teaching-learning and research environments, which likely has influenced the master students’ understanding during the bachelor part of their studies. As a first step we would like to be able to achieve a finer resolution of data with respect to how satisfaction varies, and why it is so. Engaging the academic staff in the EiT-course will most likely change the staff’s understanding of collaboration.
While the quantitative data offers some possible entry point to explore differences in students’ overall satisfaction, it is difficult to understand the underlying reasons and how different aspects of the villages, the facilitators, and the students together influence students’ learning experience. As a heuristic, we therefore used the project descriptions written by the village leaders, as an additional data source. As stated above, the project descriptions are used during the project selection phase to attract students to the different villages. The description is the first contact point for the students with the EiT course and the future project.

Looking closer at the project descriptions from the three top and bottom villages, there are clear differences in how the descriptions are written. The three villages with the lowest student satisfaction scores all had descriptions written in vague and technical language that potentially feels distant to the reader. The descriptions are impersonal and do not directly address prospect students.

Project 4:
Phosphorus is one of the fundamental elements of life and it is essential for food production. Phosphorus cannot be replaced with other elements. Despite its significance, there are few studies on the consequences of a possible reduced access to phosphorous with respect to global food security.

Project 5:
In the following, we will build on this definition. Note also that several sources use viability as a concept synonymous with sustainability. In this village, students are invited to participate in a research exercise where they will gather empirical data through the use of relevant websites, literature sources and interviews.

Project 6:
The internet can be used to obtain information about situations, and to organize and manage manpower and material resources accordingly. The management in identical situations can range from simple and straightforward instructions, to instructions for autonomous vessels and equipment.

On the other hand, the descriptions for the three villages with the highest student satisfaction are written in a way that potentially feels relevant to a large number of students. The text makes it easy to identify with the project and the information is situated in everyone’s daily life.

Project 1:
The village will work on topics related to the interactions between consumption, design, and lifestyle, and wider social trends. The groups have great freedom to design their projects themselves.

Project 2:
The brain makes us who we are, it contains our feelings, thoughts and moods. The brain enables us to travel back in time and into the future, and when you go around the world you're actually walking around in your memories.

Project 3:
The starting point for this village is to look at how this technology affects us as humans in the public space, and how the space is affected by technology. What happens, for example, to the environment in a café when all the guests bring a laptop and spend the whole day there.
These qualitative differences between the village descriptions offer an interesting alternative entry point to better understand the differences between and reasons for the students’ satisfaction with the EiT course. The differences raise questions about how the village leaders perceive their village and their own fields of research, and whether this has an impact on how they communicate about their village themes. To help the students to cooperate and become a team the village leader – the teacher – needs to be a facilitator. This is a large step for academic staff, changing from being a theoretical expert to an open-minded facilitator (Sortland & Erichsen, 2006). Due to the multiple intentions of the learning goals, the teacher needs be both a scientific expert and a mentor. How this should be performed by the teacher to maximise both the quality of the project work and the learning of teamwork skills is not fully understood, and might influence the result. It is difficult, however, to draw robust conclusions based on this information and more studies are needed to better understand what is happening in the villages. At the moment, we are able to observe that there are differences, but can say little as to their origins, or to what extent differences in attitude on how to work influence student satisfaction.

SUMMARY AND OUTLOOK

In summary, the EiT course is an example of large scale mandatory course with around 2000 students each year that promotes students’ learning of collaborative skills in interdisciplinary teams through experience based learning and reflections. A central factor on the organizational level for the acceptance of the course, its continuous development and success is a permeant unit with academic and administrative staff that focuses on the implementation and development. It is through the step-wise improvement of the boundary conditions and support material, together with the establishment of a culture around the EiT course that the course could reach high levels of student satisfaction.

On the student level, we have identified interdisciplinarity as a key factor that drives students’ overall satisfaction of the course and an increase in the perceived value of collaboration and relevance for later work life, where villages with a larger variation of disciplinary backgrounds score higher than more homogenous villages. More studies on the underlying processes for this effect are needed to better understand and interpret the situation. In the future, the interdisciplinarity index might be used to increase the variation in all villages further and provide even more students with rich interdisciplinary experiences.

Finally, the textual analysis of the village descriptions offers glimpses at the variations in how village leaders present their villages and how they might see their own role. While the village descriptions alone do not provide enough information, they point towards an interesting area for future studies. The results from this kind of studies can help to improve and develop the comprehensive preparation seminars and training, as well as support material that teachers in the EiT course have access to. These interventions can further support all teachers to adapt to their role and become facilitators for the students’ learning.

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USING ROBOTICS TO GENERATE COLLABORATIVE LEARNING, THROUGH THE CDIO INITIATIVE

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ABSTRACT

Based on the experiences of the robotics group of the Engineering School at the Pontificia Universidad Javeriana, Bogotá, Colombia, the present paper describes how the development of robotics-based projects generates active and collaborative learning that support disciplinary knowledge-building and promote the development of skills. This Student Research Group in Robotics started work in the first half of 2015 with six students and currently has more than 40, from different years (first to fifth) participating actively and with two full-time professors and two partial time professors. From the beginning, it found the potential of developing the projects and the assembly of the robots through the CDIO initiative, implemented at Electronic Engineering Program. Conceive is given by the requirements defined by the challenges request of competition. Design is done by students through teamwork guided by professors. Implement and Operate are carried out exclusively by the students, with the support of the professors. In addition to the promising and continuous good results obtained in national and international competitions in 2015 and 2016, students have appropriated the knowledge; they are responsible for their own learning and are creating permanent strategies to transfer knowledge and experience with the development of communication skills. The commitment of the professors to the group has gone beyond technical support. In addition to strengthening teamwork and values such as ethic, respect, equity, self-confidence and other responsibilities, it has achieved to empower students to assume different roles, typical of group dynamism, which has been highly valued by themselves and their families, who have told us. This paper shows the evolution of the group, which is in an exploratory stage, and a description of main features of this group such as students' roles, workspace, equipment available, and recruitment process. Additionally, we discuss how robot-based activities promote collaborative learning, through the CDIO initiative. Finally, it is detail new perspectives and the learned lessons.

KEYWORDS

Engineering education, CDIO Initiative, educational innovations, collaborative learning, active learning, Standards: 7, 8.
INTRODUCTION

Educational robotics is a term commonly used to describe the use of robots as a tool to support both teaching and learning processes (Eguchi, 2013; Keengwe, 2015). The aim of a robot-based activity is to support the knowledge building and foster the acquisition of 21st-century skills such as creativity, problem-solving, critical thinking, and communication, through manipulation and interaction with educational robots (Benitti, 2012).

Robotics-based projects offer students a concrete and tangible way to understand complex and abstract concepts. Additionally, they provide rich active learning contexts that help students make connections among concepts and facilitate the application of this knowledge to real world situations. A special feature of a robot-based activity is that it provides students with instant feedback that helps them aware of mistakes or misconceptions and to reinforce right actions.

During six years, the Electronics Engineering program at the Pontificia Universidad Javeriana program had been involved in a curricular review towards the implementation of the CDIO approach (Gonzalez, et al. 2014). The aim of this curricular review was to improve the program with a comprehensive education that takes into account the local and global context with emphasis on the process of conceiving-designing-implementing-operating products, processes, and systems (Crawley, et al. 2014). Last year, the program started the implementation of this new CDIO curriculum.

A key feature of CDIO programs is integrated learning experiences that lead to the acquisition of disciplinary knowledge and skills (CDIO Standard 7). Another key concept in the CDIO approach is active learning (CDIO Standard 8). This strategy involves students, as active participants, in their own learning process (Gonzalez, 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). Educational robotics is a strategy that facilitates the construction of rich, active learning that support disciplinary knowledge-building and promote the development of skills. From the experiences of robotics group, this article describes how the development of robotics-based projects generates active collaborative learning.

Integral formation is one of the pillars of Ignatian pedagogy (Jesuit Institute, 1993) in the education institutions run by Jesuits, that together with the Institutional Educational Project at Javeriana, promotes research training as part of this comprehensive training.

Vice-rectorate of research promotes the creation of Student Research Group. This learning community constitutes a space research training for undergraduate and graduate students. Professors and students of the University can be part of Student Research Group.

The purpose of the Student Research Group is to support the training of research competencies of undergraduate and graduate students, including the skills of inquiry, observation, recording and comparison, critical and analytical capacity, reinforcement of verbal and written communicative skills and project management, and the learning of the research process developed through the practice itself.

Student Research Group in robotics was born in the first half of 2015, with six students from the Electronic Engineering program who wish to learn more about robotics and put into
practice the knowledge acquired in their studies. Nowadays, this group has more than 40 active students, from first year to last year of engineering.

The paper is structured as follows: in the first place, it is presented a brief description of the Student Research Group. Then, it is shown the main operative features of this group such as students’ roles, workspace, equipment available, and recruitment process. After that, we discuss how robot-based activities promote collaborative learning through the CDIO initiative. It is also shown the participation in events and the outcomes. In the next section is found the learned lessons. Finally, conclusions and perspectives are presented.

DESCRIPTION AND EVOLUTION OF THE JAVEX GROUP

Robotics group has more than 40 active students, four Engineering professors and a Social Communications and Journalism professor, who helps in the strengthening of communication and diffusion areas. Percentage of women in the group is close to 25%, the same value that in Electronic Engineering Program.

The robotic group started participating in robotics competitions, which allows students to obtain results in a short time and evaluate their evolution. Competition gives the possibility to develop and strengthen some characteristics within the group members, such as cooperative learning, group work, responsibility, respect for the other and resilience. Being in line with the learning outcomes contemplated in the program are an ability to identify, formulate and solve problems engineering, ability to apply knowledge of mathematics, science and engineering, an ability to engage in lifelong learning and ability to communicate effectively.

In order to strengthen some communication skills (oral presentation, communications strategy, written communication and listening and dialog), each semester introduces new students to the robotics group (a presentation made by students group members in an auditorium), mainly first year students, who later will be trained by students of the robotic group in this semester (written and oral communication).

Student Research Group in Robotics has characteristics of learning groups that develop in the context of collaborative learning, active learning, and experiential learning as suggested by the CDIO initiative.

Due to this increase in the number of members and the limited availability of resources, we have begun to work in different areas, such as participation in other types of robotics competitions, robotic training of elementary school children and documentation of processes and results. Figure 1 shows different of these participations of the robotics’ group.
OPERATION OF THE ROBOTICS GROUP

Once good results were achieved in competitions, to robotics group was assigned its own laboratory, in which is the training track, electronic equipment and computers, components, and materials that the students self-manage, for the design and assembly of Robots, as well as for inventory management of parts and spare parts. Additionally, they are responsible for the order and cleaning of the laboratory (available to them 24 hours a day, 7 days a week). Although professors are responsible for purchasing new equipment or materials, students are the ones who prioritize the needs, based on the available budget.

Likewise, students are in charge of logistics on each trip to competitions (dates of departure and return, hotel, internal transport and transportation of robots).

Students are also responsible for recruiting new members of the group each semester. The new students must learn to program the robot (autonomous learning), then in the company of a group of students (collaborative learning) of the robotics group the aspirants must design a robot clamp, assemble it, put it to work and participate in the internal competition.

Although collaborative learning has been built on cognitive theories and in particular on knowledge in the constructivist approach, finally one must consider how each individual constructs his knowledge and learning. Gross says "the students develop their own learning strategies, point out their goals and goals, and take responsibility for what and how to learn. The role of the teacher is to support the student's decisions" (as cited in Calzadilla, 2002, p. 4).

Any person who performs the complete process of learning the programming language, design, assembly, operation of the robot and participation in the competition (regardless of
the position obtained), becomes an active member of the students group of research. Figure 2 shows a picture of the group with new members.

![Image of new members](image-url)

**Figure 2. Welcome to new members**

**METHODOLOGY**

Learning through challenges: introducing essential skills to freshman engineering students (Giraldo, Cruz & Hurtado, 2014) describes the foundations and motivations behind the efforts of last years of the Electronic Engineering Program at Pontificia Universidad Javeriana for design a course that engages students through motivating experiences in order to teach them to apply essential skills in a proper engineering context. Essential skills or also today called 21st-century skills as teamwork, written communication, oral communication, decision making, ethics, competitiveness, and cooperation.

Engineering process for the development of each robot is based on CDIO as follows: Conception starts with the requirements given in the challenge to perform. Understanding of it is done individually and later is discussed grouping what is understood to unify criteria and concepts (description of the challenge is a video in English and the students speak Spanish). In this way, it is possible to obtain a group learning and use of common language, among all the members of the robotics group, where they can openly ask and clarify their concepts. Likewise, an improvement in communication skills in English is achieved.

Then different strategies are presented, architecture of the robot and its functions. Professors are the moderators of this discussion, but students must propose, discuss, argue, and finally make agreements. Figure 3 shows students in different activities on completion field.
Design phase is done by each subgroup separately (in the conception all contribute and give ideas, but later are divided into working groups, depending on the number of people), where each one will be able to elaborate a robot according to its own design. The design of the robot should include four fundamental parts, the mechanical part, the electrical part, the electronic part and the programming part.

Design is done by the students and it must be presented to the whole group (professors and students) for evaluation and discussion. Questions are asked to the design exhibitors, by the students and teachers, in order to obtain a design that meets the characteristics given in the conception. The idea of collaborative and non-competitive work within the group is maintained.

Implementation part is done completely by the students, who must do from the mechanical assembly of the robot, until the programming of the robot commands. They have a design notebook, so that the progress, modifications, results, and difficulties presented in the process are recorded.

More experienced or advanced students in each area help to younger students or those with less experience, to learn what to do, avoiding relying on only a few people to do so.

Operation of the robots is also performed exclusively by students, some students (drivers) are training to driver the robot properly on the field, they evaluate their operation (battery life, parts replacement, performance on field) to apply improvements.

Thus, development of robotics projects, through cooperation between peers, permanent dialogue, and the possibility of putting ideas into practice, provide a collaborative learning space.
PARTICIPATION IN EVENTS AND OUTCOMES

From the beginning of the group in 2015, in national competitions has obtained a first and second place and twice the "Design Award". It has also been achieved, the classification to three world championships.

In the last World Championships, it has obtained a fourth position and the "Create Award" ("earned by a team whose robot design incorporates a creative engineering solution to the design of challenges of this year").

![Image](image.jpg)

Figure 4. World championship and internal tournament

In addition to competitions, students of the robotics group should participate in other activities, including academic events, demonstrations at fairs and school visits.

LEARNED LESSONS

This paper also wants to show that in the learning process of the Student Research Group in Robotics, that given its own nature is a work group, we consider communication in the curriculum from the nature of its structure and then we identify its possibilities as a strategy. This perspective allows the strengthening of the students’ skills in written, electronic, graphic and oral communication and multimedia, dialogue, negotiation and conflict resolution processes, and the generation of communication networks.

Particularly, the students of different semesters of the program inscribed in the robotics group during a survey to 20 of its participants stressed as achievements related to this communication skills that they had learned to communicate, listen, talk, respect and accept the point of view of others. Accordingly, 85% of the surveyed considers that their participation in the seedbed has helped them to improve their performance doing teamwork. Concerning the contribution of an effective communication on their performance, 60% of the surveyed said that it helped them completely.

These results can contribute to the permanent development and evaluation process of the program and additionally they can help to identify specific actions to strengthen the teaching and learning strategies related to interpersonal, group work and communication skills. And given the results identified in this group we find necessary to foster their motivation to strengthen these skills in order to resume the work, taking advantage of one of its merits and
the inquiries in the field that are also backed by the communicative theory that states that “thinking about communication means thinking about the non-communication” (Wolton, 2009).

**Walk through collaborative learning and other educational innovations**

Student Research Group in Robotics counts with several features not only in its shape but also on the nature of its work in science and research. First, it meets the functioning requirement of the Students Research Groups endorsed by the university. Given its origin and subsequent development it counts with characteristics, designations and others given by the theory and the learning community, group work or learning group.

Similarly, considering the nature, teaching and learning strategies available in this Student Research Group we find that several concepts appear according to the theoretical perspectives.

However, in this paper we have considered as a core concept the collaborative learning through the definition proposed by Barkley, Cross & Meyer (2014) which we have adopted for the sake of a better learning but not excluding other traits included in other concepts such as "active and experiential learning" or "contextual learning" proposed by the CDIO methodology adopted by the Electronic Engineering Program.

The contact point we want to highlight is that all these concepts, methodologies and strategies are mainly originated on cognitive development, constructivism, and social psychology theories. In this context, we find that some of the characteristics that have been developed in this group share some of the traits stemming from these theoretical perspectives.

In the survey made to 20 students, we found evidence of the way they have undertaken their work and learning process. When we asked them how they evaluate the results related to the experiences of the collaborative learning in their professional careers for being part of the Student Research Group in Robotics, 65% said that it had a high importance and 30% a middle importance.

In collaborative learning, we also consider the degree of commitment, participation, and group work expectations as important issues. Concerning the first item, 50% says that it has meet completely and 45% partially their needs. Regarding expectations, 35% considers them outgrown and 45% as fulfilled.

In the same way, concerning the role of the teacher as a process coach, we asked for the degree of satisfaction with the commitment, management and leadership of the teacher that is accompanying in the group coordination; 85% of the surveyed considered his/her work as very satisfactory. As explain Fiechtner & Davis (as cited in Barkley et al., 2014, p. 24) “the students working in learning groups like the instructor better and perceive the instructor as more supportive and accepting academically and personally”.

Regarding their answers to open questions related to their learning they stressed on the knowledge acquisition, learning to work in teams, new unexplored knowledge possibilities and the possibility to get in touch with people interested in the topic.
CONCLUSIONS AND PERSPECTIVES

The work done in the robotics group has allowed the development and strengthening of abilities and attributes, personal, professional, and interpersonal.

Collective achievements have been more favored than individual successes. This, together with the cooperative work and the very good atmosphere that exists among the members of the group, makes the group to be strengthened permanently.

Due to the size of the group, it has begun the diversification of activities, involving different types of work in robotics and other competitions and thematic, publication of papers in scientific events and more social work, which is related to the creation of open material (Written text or video) for robotics training, robotics workshops for primary school children, and creation of robotics workshops with very low-cost materials.

Robotics group will be open to students from other non-engineering programs, to disseminate knowledge of robotics and to explore the opportunity for multidisciplinary work.

As a conclusion of the benefits of this collaborative learning we can close with this remark from a student: “The Student Research Group in Robotics is not only a mean to develop our capability to work in a team, but it also helps us to acquire knowledge that complements our careers at the same time that we strengthen our values of respect, timeliness and responsibility”.

One aspect that we want to work more in the Student Research Group is the cultural diversity, equal opportunities and gender equity. Barkley et al. (2014) refer that “women, members of underrepresented racial and ethnic groups, adult and reentry students, commuters, and international students have been identified as students for whom peer and group learning seem especially valued and valuable” (p. 27).

Finally, we want to remember that we communicate due to endless reasons, but that mainly our desire drives us to communicate to share, to seduce and to persuade (Wolton, 2009).
REFERENCES


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CDIO STANDARDS COMPLIANCE: MONITORING PERCEPTION OF STUDENTS’ PROFICIENCY LEVELS

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ABSTRACT

This article presents a mechanism for monitoring a program's effectiveness in reaching its intended educational goals across the curriculum. Starting in 2011, the School of Engineering at UCSC has been implementing a CDIO-based curricular reform. Since then, we have performed a biennial self-evaluation of the Computer Science program's compliance with the CDIO standards. Along the way, we have developed tools and mechanisms to systematize data gathering for these continuous evaluation processes. In particular, we have defined three intermediate milestones at which to measure the achievement of student learning outcomes associated with CDIO Syllabus levels 2, 3 and 4, at the end of the second, sixth and ninth semesters. At each milestone, we are interested not only in analyzing data associated with traditional course-level grades, but also in how student achievement levels are perceived by students and instructors. Then, we measure the gaps between these perceptions and present them in easy-to-understand radial graphs. This information is used to detect low proficiency levels and to manage instructors and students expectations of their proficiency levels at each milestone. Also, students must have done a summer internship by the end of the ninth semester. Students must fill a self-evaluation performance survey regarding their internship, while employers must evaluate the student’s performance. These surveys focus on personal and interpersonal skills and attitudes. Again, we measure the gaps between these results. This mechanism has been applied every semester since 2015. Our preliminary results have shown that student and instructor perception of proficiency levels show a larger variance for the first two milestones. However, by the end of the ninth semester, these gaps have been reduced, which shows that both students and instructors have a better understanding of their proficiency levels. Moreover, students are slightly more critical of their competence levels than their instructors and employers.

KEYWORDS

Program evaluation, Standards compliance, Syllabus proficiency levels, Standards: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12
INTRODUCTION

From 2008 to 2010, the School of Engineering at the Universidad Católica de la Santísima Concepción (UCSC) underwent a curricular reform based on the CDIO approach (Crawley et al., 2007). This process was driven by the results of accreditation self-evaluation processes and guided by the best practices given by the CDIO Initiative, in particular the CDIO Syllabus and its 12 standards. In 2011, the UCSC School of Engineering began implementing the new curricula in its five engineering programs (Loyer et al., 2011). A central aspect of our institutional pedagogical model and of this new curriculum is the promotion of active learning (Muñoz et al., 2013; Cárdenas et al., 2013; Loyer, 2013; Cea et al., 2014; Martínez & Muñoz, 2014; Martínez & Cárdenas, 2014; Cea et al., 2015) which involves the implementation of faculty enhancement plans, new workspaces, and the implementation of program monitoring and evaluation mechanisms. These improvements were supported by the Chilean Ministry of Education MECESUP program, through grants MECESUP USC 0610, FIAC USC 1101 and PM USC 1308.

FRAMEWORK

CDIO Initiative

The CDIO Syllabus details the set of skills a graduating engineer is expected to acquire to a given degree of proficiency at the end of his studies. It classifies learning outcomes into four high-level categories: technical knowledge, personal and professional attributes, interpersonal skills and the skills specific to the engineering profession. Each category is refined to four levels of detail (Crawley, 2001). The CDIO Syllabus was revised and updated to add missing skills such as Leadership and Entrepreneurship, and to clarify nomenclature in (Crawley et al., 2011).

The CDIO standards comprise 12 guiding principles that aid curriculum design and foster continuous program improvement. These standards address program philosophy (Standard 1), curriculum development (Standards 2, 3 and 4), design-implement experiences and workspaces (Standards 5 and 6), methods of teaching and learning (Standards 7 and 8), faculty development (Standards 9 and 10), and assessment and evaluation (Standards 11 and 12). Each standard is presented in (Brodeur & Crawley, 2005; CDIO, 2010) with a description, a rationale and a rubric.

Regarding CDIO Standards compliance, our continuous program improvement model establishes biennial standards adoption reviews for our study programs. Figure 1 shows preliminary review results for the Computer Science program for years 2013 and 2015 (Martínez et al., 2013; Martínez et al., 2015). It can be seen that, in general, compliance levels for most standards are at level 3 ("Implementation of the plan to address the standard is underway across the program components and constituents"), except for standard 4 which reaches compliance level 5 ("The introductory course is regularly evaluated and revised, based on feedback from students, instructors and other stakeholders"). It must be noted that engineering programs in Chile usually are formally 6-year programs, but many students take longer to graduate. In particular, our new Computer Science program has not graduated any students yet. Therefore, the results shown in this work are preliminary.
Learning objectives evaluation model

Our learning objectives evaluation model focuses both on evaluating the coursework learning outcomes and on monitoring student progress in accomplishing the program’s learning objectives, as shown in Figure 2. At a micro level, it evaluates the achievement of each course’s learning outcome; at a macro level, it monitors the achievement of the program’s learning objectives at different program milestones: at the end of the second, sixth and ninth semesters (Cárdenas et al., 2012).

Figure 1. CDIO standards self-evaluation results

Figure 2. Learning objectives evaluation model
STUDENTS’ PROFICIENCY LEVELS FOR THE CDIO SYLLABUS

In order to guarantee the achievement of the program learning objectives, the curricular design process generated a mapping for all compulsory courses of the Computer Science program to the CDIO Syllabus skills, which, for each course, indicated whether a given relevant skill was introduced, taught or used in that course. Then, each course’s learning outcomes were defined. Later, as part of our continuous improvement process, we defined expected proficiency levels for each mapped skill, using the correspondence of MIT activity-based proficiency and Bloom scales described in Crawley as a guideline (Crawley, 2001, p. 30). These proficiency levels are shown in Table 1.

<table>
<thead>
<tr>
<th>Student proficiency level</th>
<th>Instructor opinion of student proficiency level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Not observed</td>
</tr>
<tr>
<td>1</td>
<td>To have experienced or been exposed to</td>
</tr>
<tr>
<td>2</td>
<td>To be able to participate in and contribute to</td>
</tr>
<tr>
<td>3</td>
<td>To be able to understand and explain</td>
</tr>
<tr>
<td>4</td>
<td>To be skilled in the practice or implementation</td>
</tr>
<tr>
<td>5</td>
<td>To be able to lead or innovate in</td>
</tr>
</tbody>
</table>

As mentioned before, at a micro level we assess the learning outcomes in each course, and at a macro level we monitor the students’ progression at three milestones. In particular, we wish to evaluate the development of three CDIO skills: personal and professional attributes, interpersonal skills and the CDIO skills in a real-world context, up to the third level of detail.

In order to do this, we gather the perception of student achievement levels in both students and instructors by means of surveys similar to the one presented in Appendix H of the CDIO Syllabus (Crawley, 2001) using the proficiency levels shown in Table 1. Then, we measure the gaps between the expected proficiency level and these two perceptions, presenting them in easy-to-understand radial graphs. This information is used to detect low proficiency levels and to manage instructors and students’ expectations of their proficiency levels at each milestone. It is worth noting that instructor surveys use a proficiency level of 0 to indicate that the instructor has not observed a particular skill in his students.

RESULTS

For all three milestones, a compulsory Computer Science course was chosen and both the students and its instructor were surveyed. For the first milestone, the Programming Lab I course was surveyed on semesters 2015-II, 2016-I and 2016-II. For the second milestone, the Databases course was surveyed the same three semesters. For the third milestone, the Software Engineering Lab II course was surveyed only the 2016-I semester, as it is taught only once a year. Additionally, students are required to do a summer internship at the end of the 8th semester. Both students and their employers are surveyed at the end of the internship about a reduced set of relevant CDIO skills.

Survey results for each milestone are shown in Figures 3, 4 and 5. Even though students were surveyed about all CDIO skills at the third level of detail, these figures only present the subset deemed relevant at that milestone according to the skill mapping mentioned before. Our preliminary results show that, by the first milestone, student and instructor perception of proficiency levels show a large variance between them and also with the program’s expected
proficiency level, for all three semesters. In general, students have a higher perception of their achievement levels than their instructors and the expected value. The exception is the 2016-I semester, when the course is taken by students that have already failed this course once, and their perception of their proficiency level in general is lower than their instructor’s perception. By the second milestone, students’ perception of proficiency levels is closer to the program’s expected level. However, instructors’ perception are more critical for those CDIO skills that he or she observed during the course (proficiency level greater than 0). However, by the end of the ninth semester, the gaps between the student’s and instructors’ perceptions have been reduced, which shows that both students and instructors have a better understanding of student proficiency levels. Moreover, students are slightly more critical of their competence levels than their instructors and employers.
2 PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES
2.1 ANALYTICAL REASONING AND PROBLEM SOLVING
2.1.1 Problem Identification and Formulation
2.1.5 Solution and Recommendation
2.4 ATTITUDES, THOUGHT AND LEARNING
2.4.1 Initiative and the Willingness to Make Decisions in the Face of Uncertainty
2.4.4 Critical Thinking
2.4.6 Lifelong Learning and Educating
2.4.7 Time and Resource Management
2.5 ETHICS, EQUITY AND OTHER RESPONSIBILITIES
2.5.1 Ethics, Integrity and Social Responsibility
2.5.5 Equity and Diversity
3 INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION
3.1 TEAMWORK
3.1.1 Forming Effective Teams
3.1.2 Team Operation
3.1.4 Team Leadership
3.2 COMMUNICATIONS
3.2.3 Written Communication
3.2.4 Electronic/Multimedia Communication
3.2.6 Oral Presentation
4 CONCEIVING, DESIGNING, IMPLEMENTING, AND OPERATING SYSTEMS IN THE ENTERPRISE, SOCIETAL AND ENVIRONMENTAL CONTEXT – THE INNOVATION PROCESS
4.1 EXTERNAL, SOCIETAL, AND ENVIRONMENTAL CONTEXT
4.1.1 Roles and Responsibility of Engineers
4.1.2 The Impact of Engineering on Society and the Environment
4.3 CONCEIVING, SYSTEMS ENGINEERING AND MANAGEMENT
4.3.1 Understanding Needs and Setting Goals
4.3.2 Defining Function, Concept and Architecture
4.4 DESIGNING
4.4.2 The Design Process Phasing and Approaches
4.4.4 Disciplinary Design
4.5 IMPLEMENTING
4.5.3 Software Implementing Process
4.5.5 Test, Verification, Validation, and Certification

Figure 3. First milestone proficiency level perception: Programming Lab I
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
2.1.5 Solution and Recommendation

2.2 EXPERIMENTATION, INVESTIGATION AND KNOWLEDGE DISCOVERY
2.2.2 Survey of Print and Electronic Literature

2.3 SYSTEM THINKING
2.3.1 Thinking Holistically
2.3.3 Prioritization and Focus

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, Urgency and Will to Deliver, Resourcefulness and Flexibility
2.4.3 Creative Thinking
2.4.4 Critical Thinking
2.4.6 Lifelong Learning and Educating
2.4.7 Time and Resource Management

2.5 ETHICS, EQUITY AND OTHER RESPONSIBILITIES
2.5.1 Ethics, Integrity and Social Responsibility
2.5.2 Professional Behavior
2.5.3 Proactive Vision and Intention in Life
2.5.5 Equity and Diversity

3 INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION

3.1 TEAMWORK
3.1.1 Forming Effective Teams
3.1.2 Team Operation
3.1.4 Team Leadership

3.2 COMMUNICATIONS
3.2.3 Written Communication
3.2.4 Electronic/Multimedia Communication
3.2.5 Graphical Communication
3.2.6 Oral Presentation

3.3 COMMUNICATIONS IN FOREIGN LANGUAGES
3.3.1 Communications in English

4 CONCEIVING, DESIGNING, IMPLEMENTING, AND OPERATING SYSTEMS IN THE ENTERPRISE, SOCIETAL AND ENVIRONMENTAL CONTEXT – THE INNOVATION PROCESS

4.1 EXTERNAL, SOCIETAL, AND ENVIRONMENTAL CONTEXT
4.1.1 Roles and Responsibility of Engineers
4.1.2 The Impact of Engineering on Society and the Environment

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 System Engineering, Modeling and Interfaces
4.3.4 Development Project Management

4.4 DESIGNING
4.4.2 The Design Process Phasing and Approaches
4.4.3 Utilization of Knowledge in Design
4.4.4 Disciplinary Design

4.5 IMPLEMENTING
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

4.7 LEADING ENGINEERING ENDEAVORS
4.7.8 Innovation – the Conception, Design and Introduction of New Goods and Services

Figure 4. Second milestone proficiency level perception: Databases
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
2.1.5 Solution and Recommendation

2.2 EXPERIMENTATION, INVESTIGATION AND KNOWLEDGE DISCOVERY
2.2.2 Survey of Print and Electronic Literature

2.3 SYSTEM THINKING
2.3.1 Thinking Holistically
2.3.2 Emergence and Interactions in Systems
2.3.3 Prioritization and Focus

2.4 ATTITUDES, THOUGHT AND LEARNING
2.4.1 Initiative and the Willingness to Make Decisions in the Face of Uncertainty
2.4.4 Critical Thinking
2.4.6 Lifelong Learning and Educating
2.4.7 Time and Resource Management

2.5 ETHICS, EQUITY AND OTHER RESPONSIBILITIES
2.5.1 Ethics, Integrity and Social Responsibility
2.5.3 Proactive Vision and Intention in Life
2.5.5 Equity and Diversity

3 INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION

3.1 TEAMWORK
3.1.1 Forming Effective Teams
3.1.2 Team Operation
3.1.4 Team Leadership

3.2 COMMUNICATIONS
3.2.3 Written Communication
3.2.4 Electronic/Multimedia Communication
3.2.5 Graphical Communication
3.2.6 Oral Presentation

3.3 COMMUNICATIONS IN FOREIGN LANGUAGES
3.3.1 Communications in English

4 CONCEIVING, DESIGNING, implementing, AND OPERATING SYSTEMS IN THE ENTERPRISE, SOCIETAL AND ENVIRONMENTAL CONTEXT – THE INNOVATION PROCESS

4.1 EXTERNAL, SOCIETAL, AND ENVIRONMENTAL CONTEXT
4.1.1 Roles and Responsibility of Engineers
4.1.2 The Impact of Engineering on Society and the Environment

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 System Engineering, Modeling and Interfaces
4.3.4 Development Project Management

4.4 DESIGNING
4.4.2 The Design Process Phasing and Approaches
4.4.3 Utilization of Knowledge in Design
4.4.4 Disciplinary Design

4.5 IMPLEMENTING
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

4.7 LEADING ENGINEERING ENDEAVORS
4.7.8 Innovation – the Conception, Design and Introduction of New Goods and Services

4.8 ENTREPRENEURSHIP
4.8.5 Conceiving Products and Services around New Technologies

Figure 5. Third milestone proficiency level perception: Software Engineering Lab II and internships
Figures 6 and 7 show the data distribution of student proficiency level perception for the first and second milestones. Course sizes are shown in the top row. Data distributions in Figure 6 show less variance in student perceptions for semesters 2015-II and 2016-II than for semester 2016-I. This may be explained by noting, as mentioned before, that this course is taken mainly by students that have already failed the course once. In general, data distributions for the second milestone show large variance and correspond to courses taken by less than 10 students. Also, it is more common to find the median of the student
perception of their proficiency levels at a higher value for their personal and interpersonal skills than for their skills specific to the engineering profession (level 4).

CONCLUSIONS

Even though our results are preliminary, they are useful in managing both students’ and instructors’ expectations for the student proficiency levels. Sharing these results among instructors helps them develop realistic expectations of students' proficiency levels at each milestone and take timely actions to address student shortcomings in the following courses. Sharing these results among students helps them know what is expected of them at each milestone, so students become more conscious and responsible for their expected progress in achieving the program learning objectives. To this extent, we are working on improving the dissemination of these results among students and on gathering more data so as to have statistically significant data that guides our program improvement process.

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HOW FEEDBACK ON A DIGITAL PLATFORM SUPPORTS STUDENTS LEARNING

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ABSTRACT

Students generally think they have too little feedback. This article reports on research done to evaluate how students experience the quality of feedback on a digital platform and with use of rubrics; compared to written feedback or no feedback at all. Not surprisingly, students in this research (like in other research) prefer the type that gives them most feedback. However, they prefer even more feedback that seems personal. Giving students’ feedback by indicating the quality of their solution on a detailed scale is not values as much as individual feedback that is shorter. Feedback given on a digital platform has some advances which the students think is important, such as availability, easy to find and read etc. It has also been important to investigate what happens to the quality of the feedback when given on a digital platform compared to the more traditional feedback on hand written assignments. This article is a further work on an earlier article (Lauritsen; Bennedsen; 2015) dealing with using rubrics in the same course which is the focus in this article.

In the article is also discussed if the way we give feedback is the right way. Feedback is often given as a transmission process were teachers “transmit” feedback messages about what is right and wrong in the assignments, about its strength and weaknesses, and how students use the information to make improvements in next assignment. The students have to decode and translate the messages into action. Here some mistakes might appear.

When solving problems, cases, such as those in focus in this article, the students use rubrics to get an idea on the expectations the teacher has, and use the rubrics especially to read and use the given feedback. The feedback given in the rubric is used to make improvements.

INTRODUCTION

Active learning has been on the agenda for many years (see e.g. (Cross, 1987)). In the 1980s, several reports were made in the US with the hope that universities could create teaching that actively engaged students in their process of learning (Study Group on the Conditions of Excellence in American Higher Education, 1984). As they write in the report from 1984:

"Much is known about the conditions under which student learning and growth can be maximize...We content that the quality of undergraduate education could be significantly improved if America’s colleges and universities would apply existing knowledge about three
Three conditions must be fulfilled at the same time, to ensure students learning.

1. They have to work
2. They have to be engaged
3. They have to work in their comfort zone

This has been unfolded by the Danish professor Steen Larsen (Ultimate formula to effective learning processes) (Larsen; 1998).

The first condition, “they have to work”, means they have to work with something meaningfully, it is not enough that the students are active (as sometimes are the condition in active learning), they actually have to work with activities in a particular order and a meaningfully context.

The second condition, “they have to be engaged”, means that you have to be emotionally involved, engaged, to learn in the optimal way.

The third condition, “to work in their comfort zone”, is also what Vygotsky (Vygotsky, 1962) formulated as in the “zone of proximal development”.

How does feedback fit into this formula? Well in all three conditions, we could say. The students must have some feedback on their work process to ensure they work with the most important and correct objects and in the right way. The feedback interacts with motivation and beliefs and in that way it also engages the students. Last it requires dialogue and feedback to ensure the students do work in their comfort zone.

This article focuses on feedback given on a digital platform. It has been important to investigate if it is available, useful, on time, supports the learning process and encourage the students to work with the intended objects according to the learning objectives.

Several studies have shown that feedback is very important for the student when (s)he is learning (see e.g. (Higgins, Hartley, & Skelton, 2002; Huba & Freed, 2000)). Willis and Webb (2010) defines feedback as follows: “Feedback is a term commonly used to describe the range of processes in higher education whereby a student or group of students receives information about how well they understand concepts and are progressing with their studies.” (p. 1). In studies at our university, feedback is the component that scores lowest; students do not think they get enough feedback and they need the feedback to progress through their studies. The low score on the amount and quality of feedback is also seen in other evaluations (e.g. (The National Student Survey, 2015)).

The Feedback and Assessment Benchmarking Tool (National Union of Students, 2014) developed by NUS (National Union of Students) describe ten principles of effective feedback and assessment. Some of these includes assessment criteria (the criteria should be clear, easy accessible by students and linked to learning outcomes), submission process (submission should be easy and electronically if possible) and feedback timeliness (the students should be able to act upon the feedback).
Solving a real case, where the students should find their own way and ask the right questions, they need feedback more than if a “normal” assignment where given. In a case they need to know if they have found a reasonable way to the solution. In a “normal” assignment where a model for solving has been given, the students might be satisfied with a teacher made solution and then be able to self-assess their assignment.

In this article the use of rubrics in connecting to solving assignments, cases, is described. The rubrics is seen both when the students actively solve cases and when the students receive feedback on these using the learning management system, Blackboard Learn (Blackboard, 2015). The general course design is described as well as the role of the case. The main focus of the article is an evaluation and comparison of the different feedback methods.

FEEDBACK AND RUBRICS AND THEIR USAGE

In the course used for this research, the students have to hand in four cases as a part of the learning process. The cases are mandatory and the students get marks for these and they count for 20% of the course grade. Because of the importance of feedback in the students learning process it is essential also to specify clearly the criteria used as a basis for the assessment and also to give the feedback according to these.

So we are dealing with to perspectives; the criteria in the rubrics and the feedback.

Criteria and rubrics

To clarify and specify the criteria, the teacher has in the course used the rubrics that are available in Blackboard Learn (Blackboard, 2015).

Using rubrics provides more advantages for both the students and the teacher. As described by the Eberly Centre (Teaching Excellence & Educational Innovation) at Carnegie Mellon University:

*Grading according to an explicit and descriptive set of criteria that is designed to reflect the weighted importance of the objectives of the assignment helps ensure that the instructor's grading standards don't change over time. .... Furthermore, rubrics can reduce the time spent grading by reducing uncertainty and by allowing instructors to refer to the rubric description associated with a score rather than having to write long comments.* (Carnegie Mellon University, 2015)

The students are using the rubrics both when solving the case and when reading the feedback. As one student said: “We read the criteria before, to see what the teacher expected, I mean the things we could not read from the assignment text…afterwards we mostly used the feedback and not that much the grading given”.

It makes it clear for the students how it is possible to improve themselves and it specifies clearly what are the requirements and acceptable performance standards of the cases. The use of rubrics in this course also gave the teacher a clearer picture of the student’s challenges and strengths. It is also possible for the teacher to get statistics of the class grades.
When rubrics are given to students with the assignment description, they can help students monitor and assess their progress as they work toward clearly indicated goals. When assignments are scored and returned with the rubric, students can more easily recognize the strengths and weaknesses of their work and direct their efforts accordingly. (Carnegie Mellon University, 2015).

In the course the students had to hand in four assignments (cases). In all four cases rubrics were used. The rubrics were designed as shown in Figure 1.

![Rubric for the case C](attachment:rubric_c.png)

**Feedback**

There is no doubt that feedback is very important to the students learning, there are a lots of research showing this, as written in the introduction.

Therefore it is important to find a form of feedback that is useful to the students. It has to be:

- accessible and easy to find
- understandable and precise
- clearly related to the criteria
- on time
- etc.

Race (2004) describes and discusses many different forms of feedback: oral<>written, individual<>group, hand written<>electronically.

When it was decided in the course to use the Blackboard Learn facility to give feedback, written, individual and electronically, it was based on the following:
The feedback is given in two ways in the assignments, directly in the hand-in (pdf-file) and in feedback boxes in the rubrics on the Black Board learning management platform. The feedback is given in text only, because it has not been possible to give formula and sketches.

**CONTEXT**

The course used for this research is a forth semester course on Thermodynamics at Mechanical Engineering at Aarhus University, School of Engineering. It is a mandatory course for mechanical engineering students (they need to take four mandatory courses during their fourth semester as well as a semester project). The author of this article is teaching the course, and has done so for many years. Below called, “the teacher”.

As a part of the course the students shall complete four cases. The cases are graded by the teacher. The cases are an important part of the learning process in the course; it is where the students have to do calculations on realistic problems and here they are forced to read the learning material more in depth. In the evaluation of the course almost all students state that this is where they learn mostly - and also state this is hard work. Due to the importance of these cases, a lot of effort to give the students proper feedback.

The four cases in the course are somewhat different in form and content. It is debatable whether the four issues in their form actually meet the definition of a case.

Lau (Lau, Woon M. L. 2007) write: … “in Case Based Learning (CBL) the problem space is defined by the case. Typically, the presentation of the problem comes first in the CBL instructional sequence, which is a reversal of the traditional use of problems in science teaching. The introduction of a case (Lau, 2007) problem early in the instructional sequence encourages learners to use the case to generate a set of questions that they then try to answer. This makes them more motivated in subsequent lectures, labs, and discussion because they have a problem of their own to work on. In short, students are asked to learn new materials mainly by themselves, and also to pose intelligent questions, develop accountable approaches to investigate these questions, and present their methodology and conclusions to the class”.

A case has to be a real problem which is presented by a realistic (or real) story. With this story as base, a question (or a series of) is formed for the students to answer. These questions should help the student create a number of hypotheses and questions to validate the hypothesis, thereby fostering new knowledge. The first case in the course is in that sense not a real case. It is more a design assignment and some disciplinary questions connected to this. In this case the students have to make a poster. On the poster they have to describe an energy system by function and energy balance.
The last three cases are formulated as cases, that is, they have real stories as a basis. But in the text very specific questions are formulated, that in some way guides the student through the problem solving. The student does not really have to generate their own hypothesis and questions. The cases are chosen from the course content to cover different topics.

The feedback is given on the Blackboard Learn platform (Blackboard, 2015). In this paper it has been described, elaborated and evaluated on the feedback given.

Feedback is given in two ways, see Figure 2.

1. **In the boxes in the rubrics**: Here more general comments to form and method e.g., are given. Here only text is possible.
2. **Comments in the pdf-file**: Specific corrections into the substance are given. The facility in Black Board does not support tools to make sketches and formulas in a proper way, so the comments are only in text form.

![Feedback in Blackboard. Left; comments in the pdf-file. Right; feedback in rubric boxes](image-url)
RESEARCH DESIGN

The research is done in a real setting - a real course with real students. An alternative to this could have been to ask students for their view on the feedback given. The rationale for choosing a real course is that it gives a much more realistic view on how feedback on the digital platform is perceived. One downside of this design is that students might have difficulty in just focusing on the feedback – it is of course seen as a part of the learning design. It is found that the research design is good but one need to take the concerns into account when analyzing the results.

The research question in focus here is “How do students perceive the feedback given to their case work - both the feedback in the pdf-file and in the rubrics? And how do they perceive feedback on the digital platform compared with feedback in traditional form?”

In order to evaluate how the feedback is perceived, it has been decided to interview a group of students and beside this to look into the evaluation form from the course. The students participating in the interviews were chosen by random (out of a total population of 42 students for the course). They were not given any credit for participating in the interview. It is important to notice that the interviewer is also the teacher. It of course lowers the potential impact of the work.

Research method

Here has been used primarily a qualitative philosophy well aware of the strength in using also a quantitative method. To compensate for this the course evaluation has been taken into account.

Course evaluation

In the course evaluation which took place in the end of the course statements, feedback on cases have been picked up and some useful comments and interesting points have been found.

The evaluation was designed as a form handed out in class with two boxes. In one box the students have to write down three good things about the course and in the other box three things that can be improved. In this design the students get to find precisely the things they feel is good or has to be improved, and not the teachers formulation of the things he want to focus on as it is on some questionnaire.

Interviews

Prior to the interviews an interview guide has been prepared as a framework for the interviews. The interview guide consists of keywords, which are prepared in preparation for the interview. The guide worked well, and the order was almost followed.

The interview began with a brief introduction to the purpose of the interview. As a starting point questions about the age and prior knowledge about the field as well as if the cases were done alone or in collaboration with a fellow student has been given. After that the interview got into asking about the feedback given:
• Quality of the feedback given, was it useful and relevant
• How did they use the feedback
• Where the feedback understandable
• Where the feedback timely
• Did you get enough feedback
• Balance between positive and negative feedback
• Problems finding the feedback
• Differences in feedback given in the pdf-file and in rubric boxes
• Usage of rubrics for feedback from the teacher
• The learning management system
• The structure of the course (including the cases)
• General comments

The interviews were recorded on audio files.

Participants

42 students participated in the course. Out of these were four female. The interviewed students were all male. Eight students were interviewed. The interviews were done in the week after the examination. The students were random chosen from the course participants. The students were from 22 to 28 in age, all of them in their second year of their bachelor study.

Analysis of the data

The qualitative data were analyzed by the author. The author listened to the interviews and noted relevant views on the general topics.

There has been no transcription of the interviews in their entirety, but condensed view of relevance to my perspective in the study. Specifically keywords from the interview guide have been used to first organize and then condense the eight interviews. By selecting this method awareness has been given to some errors that may affect the conclusions, especially because the teacher and the interviewer are the same person in the course. Also some mistakes could appear because of translation to English and some meaning might get lost. This was considered acceptable as what was wanted to retrieve from the interviews are general views and status more than it is facts. Furthermore, a mix method approach has been used and can compare the findings in the interview with what has been found in the course evaluation form.

FINDINGS

The students have not been exposed to rubrics in this form in earlier courses, they found it very useful that the expectations were precisely described and that the rubric expressed the expectations very clearly. When in the interviews was asked about how they normally find the information, most of the students said that the types of assignments they normally have, typically calculations - apply the theory to a problem and calculate something. For this type of assignments, they know what they are expected to do. They found the criteria understandable and precise, and this compared to the given feedback was important and useful.
Some students though said, they were able to read from the case text what they were supposed to do, and did not use the criteria that much before solving the case just afterwards when feedback was given.

**FEEDBACK**

As described before, is have been evaluated how feedback is perceived by the students. When giving feedback the rubric was used to structure the feedback. But did the students read the feedback and did they use it for improvement?

From the interviews it was clear that the students read the feedback and that it was very useful. One student put it this way: *this getting feedback is really what you learn from… what I could have done different, and so…*

All students stated that feedback on the digital platform was a good way to give the feedback. They did especially think the feedback given in the hand-in file were useful. As some students said:

*…it showed me specific what I had done wrong and mistakes I have done… one has it all at your fingertips and can use it later… it is easy… we have not received feedback on a digital platform before… I think it is very good…*

The comments given in the boxes in the rubrics, some could not use in connection to the specific case, because it was comments to method and strategy. Some students stated this was more useful in connection to the generally understanding in the course and solving the next cases.

Another student put it this way:

*…boxes with general comments might have been more comprehensive and detailed because I can use it further on … references to where I could read more about it and some examples…*

The students indicate that they receive much more feedback and with a higher quality in this course than other courses. In many courses they did not get any feedback at all. *…in fact, it is in this course we have had most feedback on work we have done… and it is important it comes from you and not from other students…*

From what has been found from the interviews, a comparison of feedback on a digital platform and the traditional way has been made. It is shown in following table, Table 1.
Table 1. Positive and negative opinions about digital feedback

<table>
<thead>
<tr>
<th>Positive on digital feedback</th>
<th>Negative on digital feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Students</strong></td>
<td><strong>Teachers</strong></td>
</tr>
<tr>
<td>Easy to find feedback</td>
<td>Only text comments and corrections, sketches and formulas that explains how to improve is wanted</td>
</tr>
<tr>
<td>Feedback is saved for later use</td>
<td>Did not have that much dialog with the teacher about the hand-in feedback, because the communication was only on the Black Board platform</td>
</tr>
<tr>
<td>Feedback is saved same place as hand-in and assignment</td>
<td></td>
</tr>
<tr>
<td>Feedback was easy to read because of digital text</td>
<td>Did not have that much dialog with the students about the hand-in feedback, because the communication was only on the Black Board platform.</td>
</tr>
<tr>
<td>Saves paper, energy and time for printing</td>
<td>It mostly becomes “find the errors” and not that much explanations to help the students to improve and learn by this</td>
</tr>
</tbody>
</table>

...if you make a pdf with feedback it tends one does not do it just as well as if it’s done by hand where you are able to striking out and making a little drawing and so… one student stated.

**DISCUSSION**

Students favor detailed criteria. It is clear from this research that the feedback they liked the best were the personal feedback given precisely into where in the assignments they have made errors or misunderstandings. That means that the feedback given into the pdf-files handed in was the most useful. The more general comments made in the boxes in the rubrics where used for the more principle issues on the methods and strategies when solving the next case.

But is it the right way we are giving feedback like in this context? Does it support the learning process in the way we want? It seems we are taking the student by the hand and lead them to the “right way”, this transmission way, were teachers “transmit” feedback messages about what is right and wrong in the assignments, about its strength and weaknesses, and how students use the information to make improvements in next assignment. The students have to decode and translate the messages into action.
If we want to support the learning process, we might use more of the guiding version of feedback, like. *Here in this section of the calculation you have used… read more about this in…*

Then the assignment could take another round and have new feedback. Use of peer-assessment or self-assessment could be other way to improve and the feedback would be different. In “Seven principles of good practice” (Nicol; Macfarlane-Dick; 2006), good suggestions on how to improve the feedback process in my course is given, it might be a way to go.

All in all some more interaction and dialog could support the learning process better.

**CONCLUSION**

As concluded by many others: Feedback is useful and appreciated by the students. In this course the students found the amount of feedback to be higher than they normally experience in their study. One student put it this way: *There is much feedback in this course compared to others. Normally we do not get feedback, that we do not like and normally we do not have so many mandatory assignments, which was good.*

The students like to have a detailed description of their assignment. However, personal feedback was preferred even more. When the students were asked about their view on the feedback given by indicating the quality of their solution on a detailed scale, they preferred the individually written one. All of the interviewed students said that the setup with cases, rubrics and feedback on Black Board was very good and helpful. Here some citations:

*…it is a good way to do it, this, solving cases, you just stop and think about what you have learned and what the teacher went through in class…*
*…in fact, I think this hole set up is very fine, this that it is online and we can hand in this way that we could see what was expected and afterwards have feedback and see if we did do it ok…*

The students like to have feedback on a digital platform. It is easier to find, it is saved for later use, and it saves paper, energy and time to print. It also mostly is easier to read because of digital text instead of handwritten comments. You have hand-in, assignment and feedback saved in the same place.

What the students think could be useful and what are not available until yet, were sketches and formulas that explained their mistakes and how to improve in the best way. Also some of the students thought that the traditional hand written included more dialog with the teacher, which is good.

Final comment from a student: *…its very fine with this feedback on a digital platform, but it cannot stand alone … there must be dialogue with a teacher…*
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EXPERIENCES OF EDUCATIONAL REFORM
– IMPLEMENTATION OF CDIO AT INDUSTRIAL
DESIGN ENGINEERING

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Innovation and Design, Luleå University of Technology

ABSTRACT

Luleå University of Technology (LTU) joined the CDIO initiative in 2015. The development of the MSc program Industrial Design Engineering (IDE) was one of LTU’s four test pilots of educational reform with support of the CDIO framework. The current educational reform comprises all CDIO standards, however some have been easier to implement than others. The results from the current CDIO-implementation are so far positive experiences from both faculty and students. While the program curriculum has been developed at a macro level, changes also impact the program objectives, teachers’ skills development, and students’ learning outcomes at a micro level where, for example, courses have been redesigned regarding teaching and learning activities, and assessments have been developed to include both formative and summative feedback to promote a deep learning approach. Great efforts have also been put into development of new learning environments, finalized in 2016. However, implementation of CDIO also deals with changing the educational culture, a work that takes more efforts and time than this current two-year reform. A success factor in the present implementation is the involvement of experienced CDIO-implementers that have inspired, motivated and coached the IDE faculty in re-designing the program.

KEYWORDS

Educational reform, CDIO implementation, Active learning, Standards: 2-10

INTRODUCTION

The focus of this paper is educational reform with support of the CDIO approach, implemented at the MSc in Industrial design engineering program (IDE) at Luleå University of Technology (LTU), Sweden. The IDE program integrates industrial design with engineering design, and with human needs and requirements as main incentives for development of students’ products, processes, and systems building skills. By tradition, various subjects such as usability, aesthetics, design methods, ergonomics, human work environment and design theory has been interspersed with more traditional engineering subjects such as math’s, physics, solid mechanics, material science etc. Simon once stated “the engineer, and more generally the designer, is concerned with how things ought to be - how they ought to be in order to attain goals and to function” (1996 p. 4-5). A design engineer should hence also in
our view not be concerned with “what is”, other than identifying human product, process or system needs, but with creatively applying a “what if”- mindset, supporting future innovations. The program outcome is a design engineer, a person who over the 33 years the program has existed has been highly attractive in the labor market for e.g. great visual communication skills, creative and innovation capability, as well as great ability to coordinate and collaborate in projects.

However, a program evaluation performed by the Swedish Higher Education Authority in 2013 considered IDE to have poor scientific base. Additional reviews among IDE student, faculty, and external stakeholders identified that the curricula was not considered to be constructively aligned. External IDE stakeholders considered the main program parts relevant, but with possibilities of improvement in terms of more focus on progressing students’ skills in e.g. entrepreneurship, sustainability, and interaction design. Before the Swedish Higher Authority evaluation, teachers were relatively autonomous in choosing teaching and learning approach, as well as in setting their own course objectives and examination forms. This was also identified as a challenge in order to reform the education towards student-centered constructively aligned learning experiences, rather than the previous teacher-centered learning approach. A core of the IDE faculty initiated the reforms inspired by what Crawley, Malmqvist, Östlund, Brodeur and Edström (2014) describe as a good approach: 1) we arranged workshops in which first faculty and later students worked with the CDIO standards in order to better understand what they covered and how they could be implemented in our context; 2) we arranged meetings with students and external IDE stakeholders, in order to identify both students’ and the professional IDE practice’s needs; 3) we visited other universities that had implemented CDIO; and 4) we invited CDIO knowledgeable persons to help us coordinate and coach the implementation process. In upcoming sections we outline some of the CDIO standards and describe what has been done in order to change the IDE educational culture.

**Integrated curriculum (Std 3), Introduction to Engineering (Std 4), and Integrated Learning Experiences (Std 7)**

Standard 3, 4 and 7 incorporate a curriculum designed with supporting disciplinary courses, integration of learning experiences, as well as integration of both personal and interpersonal skills, and product, process, and system building skills, as well as providing an introductory course accommodating a framework in industrial design engineering practice (Crawley et al., 2016). At IDE, the first two years in the previous curriculum contained a lot of diverse courses, e.g. maths, physics, economics, as well as ergonomics, design methods, aesthetics, sketching and prototyping. In the current CDIO implementation we for this reason developed a 15 ECTS *Introduction to IDE* course, with the idea of integrating disciplinary knowledge with practical skills-development, and of providing a framework for industrial design engineering practice. This course includes several design-build experiences, implemented in small-scaled projects, for students to practice both personal and interpersonal skills. The teaching and learning approach includes flipped classroom, which in this course is implemented through reading instructions as well as watching video-clips before class, and practical exercises, labs and group assignments during teacher-student interaction. It also includes formative feedback (Biggs & Tang, 2011) as students hand in a first draft of each assignment, receive feedback from both peers and teachers, and then have the opportunity to act on the comments before summative assessment. The learning objectives have been revised to better align with the CDIO syllabus, and to form a rational, consistent and detailed statement of competences for an industrial design engineer (see Wikberg Nilsson & Törlind,
This has been part of a strive to develop an educational culture that supports development of self-regulated learning strategies through a focus on professional qualifications and intended learning outcomes as the object of learning (see Wikberg Nilsson & Gedda, submitted 2017). The students showed approval of the new course design with practical classes and workshops:

“The project-based learning approach was very helpful in connecting all industrial design engineering competences”

(IDE student Year 1 - autumn 2016- author’s’ translation)

A self-evaluation of the involved standards is that we have developed and implemented an integrated curriculum concerning personal, interpersonal, product, process, and system building skills development. There is evidence of the impact of the implementation of integrated learning experiences, even though we need to continue in developing the teaching and learning activities, and there is documented evidence of students having achieved the intended learning outcomes of the introductory IDE course.

**Design-implement experiences (Std 5)**

Standard 5 deals with development of a curriculum that includes design-implement learning experiences (Crawley et al., 2014). Where the previous curriculum offered a clear distinction between theoretical and practice-based content, the redesigned curricula integrate these to progress students’ design-build learning experience early in the education. The introductory course year one now integrates theories of design methods and project management, with both sketching and prototyping learning experiences. The idea was that theories of design methods and project management are best learned through implementing a project, thereby also developing both personal and interpersonal skills. The second year 15 ECTS course also offer an integrated course design with design theories such as semiotics, aesthetics, usability, and user experience integrated with practice-based skills-development in prototyping and model making in the workshops. These two courses have so far been implemented only one time, and there are, of course, room for improvement. However, the course evaluations show that the idea of integrating more theoretical knowledge development with more practice-based ditto is approved by the students.

“The design-implement experiences of creating and developing several concepts have been implemented in the whole course through all the tasks and assignments. It has consisted of creating ideas, sketching them, or prototyping them. An idea or concept is always good to develop to see if it can become something even better. A prototype should be evaluated and re-developed to obtain such a good end result as possible.”

(IDE student Year 2 - January 2017 - Authors’ translation)

Given the nature of the competences that IDE students should develop, we believe that the design-implement skills development progress that starts day one in the program lay the ground for a good progression of skills throughout the rest of the program. For these reasons, we consider that there is documented evidence that students have achieved the intended learning outcomes of the design-implement experiences.

**Engineering workspaces (Std 6)**

Standard 6 address engineering workspaces and stipulate the objective of the learning environment as "engineering workspaces and laboratories that support and encourage
hands-on learning of product, process and system building, disciplinary knowledge, and social learning” (Crawley et al., 2014 p. 131). In 2016, LTU declared the vision of becoming Sweden’s best learning environment. Rebuilding of workspaces is conducted in order to attract students and also to challenge what Fischer (2005) describes as a university tradition of focusing on learning spaces’ technical performance rather than pedagogical effectiveness. Fischer emphasizes that a learning environment should promote independence and self-motivation, that students’ needs should be reflected in the learning program, and that students should be challenged and supported to develop deep levels of thinking and application. A re-design of formal learning spaces for disciplinary knowledge and practical skills-development such as classrooms, design labs, workshops, project rooms, meeting rooms, as well as informal learning environments for practical skills-development such as study areas and cafeterias was initiated in 2014, and finalized in its current state in March 2016. The new IDE learning environment has taken much faculty effort during the past years, to ensure best possible teaching and learning practice. The new learning spaces encourage hands-on learning, support both disciplinary and interdisciplinary knowledge, and facilitate group activities and social interaction. All students have full access between 6AM and 11 PM. One example is one of the IDE design studios that is designed as a very flexible space, that rapidly can be transformed from a classical presentation hall for 90 students to interactive group work by using stackable tables stored in the ‘garage’ (see Figure 3, a large storage area with tables, whiteboards, workshop material, easels etc.). This enables teachers in design courses to go from presentation mode (see Figure 1) to group work (see Figure 2) in a couple of minutes, thereby allowing the students the opportunity to test and implement the previously presented theory. The new learning environment has received very positive feedback from both students and faculty, and LTU also arrange study visits to the IDE learning environment from other universities, in short: we have evolved the IDE learning spaces into an environment LTU is proud of, and want to show to others, see Figure 1-6. Some of our IDE students’ state:

“We consider it to be much more student-oriented now, compared to before. It is more flexible; the different workshops, the 3D prototyping spaces, the usability lab, the design studio in which we can build full-scale prototypes, and we have access to all facilities all-day so you can use them. We also have much more student-spaces compared to the previous facilities, is so much nicer now!”

(IDE students Year 5 - January 2017 - Author’s translation)
Figure 3. The ‘garage’: a large storage area that stores a full-scale driving simulator along with lots of other material.

Figure 4. IDE student working with a clay prototype in one of the workshops.

Figure 5. IDE using the wall to present project progress in one of the project areas.

Figure 6. Mockup of a truck cabin in the IDE design studio.

Figure 7. Informal learning environments at IDE: cafeteria and study-spaces.

Figure 8. One of the workshops in use- illustrating practical design-implement experiences.
In summary, we consider that our industrial design engineering workspaces fully support all components of hands-on, knowledge, and skills learning.

**Active Learning (Std 8)**

CDIO standard 8 prescribe that teaching and learning should be based on active and experiential learning methods (Crawley et al., 2014). Crawley et al. further state that “inherent in any active learning method is the fact that students actually do something” (p.154). The aim of the new integrated courses and the reformed curriculum is to deepen the student learning experience through integration of disciplinary theoretical and practice-based contents. The students are now given an increased number of assignments based on active learning in which they need to identify and conceive theoretical knowledge, but also have to proceed to design and implement in order to complete the task. The assignments are now performed both individually and as team assignments (3-5 students) and require the students to develop both personal and interpersonal skills, such as to coordinate and collaborate, in order to succeed. We believe this to be a realistic approach to develop their professional practice skills, as they are exploring new concepts, identifying problems, and/or exploring new ways of working. Formative feedback (Biggs & Tang, 2011) has in all IDE specific courses been implemented in order to progress students learning. In several of the courses we have also implemented different forms of blended learning in which teachers record their lectures, require students to watch the recordings before class, and spend class interactions on feedback and discussions instead, as shown in the following quote:

“It was a good thing to first get a short instruction [by the teacher] and then perform a task right away, instead of listening to a teachers for hours and hours. /.../

For me this has contributed to a good learning experience, as the principal of "learning-by-doing" works for me.

(IDE student Year 1 - Jan 2016- Authors' translation)

The design projects given to the students vary between 2-hour speed tasks, and 20 weeks half-time pre-professional independent skills-development with external clients in the final year 5. External client companies are now also part of the first introductory course, in order for student to realize the IDE context and framework provided by the education. Several of the courses now have workbook assignments, which require students to reflect on their learning experiences in the TLAs. In conclusion, active learning methods are now being implemented across the IDE curriculum.
Enhancement of faculty competence (Std 9) and Enhancement of faculty teaching competence (Std 10)

Standard 9, according to Crawley et al. (2014) deals with enhancement of faculty competence in personal and interpersonal skills, as well as product, process and system building skills. The overall objective of standard 10 is to take actions that enhance faculty competence in providing integrated learning experiences, in using experiential learning methods and in assessing student learning. The review of IDE performed by the Swedish Higher Education Authority in 2013 identified a lack of scientific base in the program. Contrary to statements of incentives for the CDIO initiative (Crawley et al., 2014), many of the courses in the previous curricula were practice-based with little or non connection to theories. This can be seen as in line with the CDIO approach, in the sense of developing engineers who actually can engineer, but we identified the conditions to be more of teachers taking over courses from previous teachers, without reflecting on the need for educational development. As a result, a professor was employed in 2015, to handle the overall strategic development of faculty competences. This has resulted in a series of IDE faculty seminars, with discussions of the research basis of what we do in our courses. The outcome of this is so far a pleased faculty, who now spend time on discussing what we do (disciplinary knowledge), why we do it like that (pedagogical theory), and alternative approaches based on current research and/or best practices.

In the reform, we identified a need to facilitate both faculty understanding of IDE specific conceiving- designing- implementing- operating skills, as well as an understanding of the overall CDIO intentions. For this reason, a faculty course in program-driven course development was developed by LTU’s Educational Development Unit, in which eleven IDE teachers participated. During the course the teachers worked with course development projects inspired by the CDIO initiative, supervised by experienced CDIO-implementers. The teachers’ course development projects now has been implemented in IDE courses. Also, faculty members responsible for the IDE CDIO implementation completed courses in Pedagogical Leadership and Strategic Pedagogical Development. In addition, a highly-appreciated workshop with professional IDE practitioners was implemented in March 2016, an activity in which both teachers and students participated on even terms. This led to further discussions about skills-development and faculty competences and planning of more IDE workshops. Some of the faculty also visited Industrial design engineering at TU Delft and Chalmers, similar educational programs that have various solutions to learning integration for example. The outcome of this is a range of re-designed courses, however, the ideal outcome of increased student skills-development needs more time.

The IDE faculty prior to the CDIO implementation had little pedagogical training, with a few exceptions. There was an unspoken understanding of delivering courses as the faculty had been taught themselves, meaning based on an expert teacher who transform his or her knowledge to the students. The CDIO implementation really turned this around, as highly CDIO knowledgeable Kristina Edström contested the IDE faculty teaching and learning practice, and supported the faculty in understanding how TLAs could be implemented differently, without having to spend more teacher resources. In summary, actions to enhance faculty competence in teaching and in personal and interpersonal skills, as well as product, process, and system building skills have resulted in increased understanding of the CDIO incentives through activities such as discussion seminars, benchmarking IDE educations, concrete course development of integrated learning experiences, and skills development workshops with active practitioners. Faculty members now also continuously participate in development of teaching, learning and assessment methods.
Learning Outcomes (Std 2) and Learning Assessment (Std 11)

In this paper, we coordinate our work with implementing Standards 2 and 11. On a macro level, this has resulted in the development of a competence profile for IDE-students, consisting of 8 critical competences for developing both personal and interpersonal skills, and product, process and system building skills, as well as disciplinary knowledge (see Wikberg Nilsson & Törnling, 2016) which should be consistent with program goals and learning assessments. The idea with this is to convert CDIO intentions, into a practical everyday tool that both teachers and students can implement in teaching and learning activities. In one IDE course, students implement the competence profile to self-evaluate their own competence and skills, and review other’s self-evaluation and give feedback. From the course evaluation the students say they appreciate the self-evaluation, and especially the possibility to peer-review others assignments.

"[This was] a difficult but good way to reflect on my own and other team members contribution to the project!"

"[This was] a good opportunity to remind yourself about your own contribution to the team"

"[It was] fun to evaluate my own and others' performance in the course (IDE students Year 3 - Jan 2016- Authors’ translation)

The competence profile provides a focus on the particular objects of learning for IDE students (see Wikberg Nilsson & Gedda, submitted 2017). The development of the competence profile included prototyping the artefact in learning activities, and exploring how it contributed in strengthening students’ self-awareness of the professional identity as industrial design engineers. On a micro level, the competence profile assembled teachers and students’ understanding and contributed to informed actions in TLAs. In summary, the competence profile not only supports students’ self-awareness and guides their actions, but also helps teachers in creating learning experiences that subsidize students’ understanding of the professional engineering role and thereby back in taking steps for change of the educational culture.

In addition, the learning assessment in several of the IDE courses have been developed to better progress students learning (formative feedback described in Std 8), and to self-evaluate their IDE competences. This is the result of much discussion of what to actually assess, the process or the results, and how high IDE-quality can present itself in students’ hand-ins and assignments. The curricula have been scrutinized in order for students to meet various types of assignments and assessments, and for the assessments to contribute to a progress of learning in a constructively aligned learning experience throughout the program (e.g. Biggs & Tang, 2011). Now, one year into the current CDIO implementation, our learning assessment methods are much better aligned with the learning goals across the curriculum.

DISCUSSION

In a continuous educational improvement process, as described by Crawley et al. (2014), we have now completed a full circle of 1) input: better understanding program purposes, resources and activities, 2) implementation in form of actual teaching and learning activities, as well as identified program outcomes in form of 3) impact, and used the results of course evaluations and student program committees to plan for new 4) improvements. Having completing a full circle have made us realize what we have achieved so far, but also how
much work that is left to be done. Within the CDIO implementation project, it has been highlighted that general engineering courses should be more integrated and adapted to the specific programs. The general engineering- and specific IDE, courses in the current curricula run in parallel, and we have now started to investigate how the general engineering course content can be better integrated to the IDE program.

On a macro-level, there is a need for a reform of the educational framework to reward teacher excellence, and other pedagogical development, and to upgrade pedagogical educational development in promotion and recruitment. During the CDIO implementation we have continually addressed teachers that consider educational development neither as important, nor as rewarding. Today there is a lack of incentives for educational change, and other aspects of faculty work [read research] are considered more important. An important aspect in this is that a CDIO implementation deals with a change of the educational culture. The previous IDE educational culture was that of autonomous teaching and learning cultures, often realized as one teacher - one course, lacking a constructive alignment in curricula. With a CDIO approach, such previously quite autonomous teachers now need to adapt to overall program objectives and implement changes. Mintzberg (1978) describes this as one of the main challenges in educational reform and that is something we agree upon. Also, universities are by tradition resistant to change (Crawley et al. 2014), but through an understanding of the need for change, and by forming a group with enough power to lead the change effort (Kotter, 1995), change can be accomplished. At IDE we initiated the change in the courses that we have access to, with the intention of gradually changing the educational culture through both faculty and students that have developed an understanding of the CDIO approach and its prospect of improving the quality and nature of the IDE education. Another learning is that participating several faculty members in the CDIO implementation seminars and course, had several advantages: it allowed for discussions of CDIO skills and how they can be demonstrated, of how an integrated learning approach could be implemented at IDE, and how a consequent constructive alignment of learning experiences could be implemented in the curriculum. Table 1 illustrates a self-evaluation of the IDE education in 2015 and one year later in 2016. There is still work to do in order to actually change the educational culture at IDE. So far we have taken the first steps towards a full implementation of CDIO.

Table 1. Illustrates a self-evaluation of the CDIO initiative at IDE

<table>
<thead>
<tr>
<th>Standard</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>2016</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
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<td>3</td>
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</tbody>
</table>

The educational reform is expected to result in program outcomes that meet national standards of engineering education, and that provide learning experiences that motivates students to approach self-regulated deep learning strategies and thereby also retain students in the engineering practice. A conclusion so far is that educational reform deals with development of an educational culture. It takes much more effort than anyone of us previously had understood, but at the same time is much more rewarding in terms of students being motivated and committed to the program. All CDIO standards needs to be continuously addressed in faculty and among students in order to actually be implemented in the everyday teaching and learning practice. The current work has resulted in Swedish Higher Education Authority approving IDE as a high-quality education. We do however not want to stop at this approval: we want to be one of the best IDE programs in the world, educating creative individuals who contribute in solving both current and future challenges. In
this paper we have presented our first steps towards educational reform, what Crawley et al. (2014) describe as the development of a framework that provides a sequence of learning experience that meet students’ learning needs, and that promotes deep learning of [industrial design] engineering fundamentals, through pedagogical approaches and innovative teaching methods, in new learning environments that provide concrete learning experiences.

REFERENCES


BIOGRAPHICAL INFORMATION

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INTEGRATION OF GENERIC SKILLS IN ENGINEERING EDUCATION: INCREASED STUDENT ENGAGEMENT USING A CDIO APPROACH

Thomas Mejtoft & Jimmy Vesterberg
Umeå University

ABSTRACT

To be able to successfully pursue a future career within engineering, students need to acquire not only disciplinary knowledge but also generic skills to become professionals. The CDIO model provides a foundation of generic skills that can be expected by the students’ future employers. This paper presents pros and cons when integrating generic skills in disciplinary projects and is based on surveys and interviews with students and teachers on two integrated courses, Project management and Interactivity in smart environments, on an integrated five-year Master of Science program at Umeå University.

The results show that integrating two courses to give disciplinary meaning to projects make the students maintain their motivation during the course in Project management. In addition, the integration of the courses led to more time for the students for the actual project work. Lastly, both students and teachers also had the possibility to provide a better formal project structure on the disciplinary course. However, the results also show that the confusion among the students increased due to different requirements in each course. Thus, a high level of communication and a holistic view among the involved teachers is desirable to improve the overall success in course integration.

KEYWORDS

Project management, Case-based, Project work, Standards: 1, 2, 3, 5, 8, 11

INTRODUCTION AND THEORETICAL FRAMEWORK

Engineering education with a close connection to future profession is important and popular in many parts of the world. To be qualified for a future career as an engineer in the 21 Century, not only the disciplinary skills needed for a certain line of work is important for building the necessary professional skills but also generic and inter-disciplinary skills (e.g. Mechefske, Wyss, Surgenor & Kubrick, 2005; Schwieler, 2007). Generic skills are defined as “those which are achievable, worthwhile and essential for all undergraduate students regardless of their course of study ... they underpin education and provide a basis to support lifelong learning” (Wright, 1997, p. 51). The high demand of a wide variety of skills on graduated students also put a huge pressure on education programs and individual teachers to give the students a possibility to learn both a broad range and the right set of skills during their training (Mechefske, Wyss, Surgenor & Kubrick, 2005; Schwieler, 2007). To cope with
this and educate future engineers, the CDIO model (Crawley, Malmqvist, Ostlund & Brodeur, 2007) provides a broad base for the generic skills that can be expected by both current and future engineers and with the right design and implementation, a wide range of the personal and interpersonal skills stated in the CDIO syllabus can be met.

Asking future employers of the engineering students and professionals within the discipline, project management skills and communication in foreign language (i.e. English) are always stated among those important generic skills necessary for the students to learn (e.g. Pant & Baroudi, 2008; Stevenson & Starkweather, 2010). This corresponds well to the second paragraph of the CDIO Syllabus 2.0 - Interpersonal skills: Teamwork and Communication. Nevertheless, in engineering education, project-based learning in a common, and appropriate, way to integrate the skills needed as a professional engineer, both disciplinary knowledge and generic skills (De Graaff & Kolmos, 2003; Mills & Treagust, 2003). Motivation is important when achieving goals and can be defined as “the process whereby goal-directed activities are instigated and sustained” (Schunk, Meece & Pintrich, 2014, p. 5). To focus teaching and learning around projects may also increase the students' motivation regarding their own learning process (Turner & Paris, 1995). Furthermore, integration of generic skills in disciplinary courses might increase students' motivation and give disciplinary knowledge more realistic contexts (Mejtoft, 2016), which makes the relevance of the project's outcome important regarding e.g. a social and business context (Cardozo et al., 2002). Previous research has shown that having real-world projects deeply integrated in education and using inter-disciplinary skills in solving disciplinary problems both increase the students motivation and give the students a better focus on professional, value-based, problem solving (Mejtoft, 2015; 2016).

This case study illustrates and analyzes how setting up a touch-point between two courses in a project work can push the education further towards the ideas of CDIO. The paper seeks to present pros and cons when integrating generic skills in disciplinary projects and is based on surveys and interviews with students and teachers on two courses. Using project-based learning is something that has been deemed appropriate and successful in engineering education (De Graaff & Kolmos, 2003; Mills & Treagust, 2003).

**METHOD AND STUDY DESIGN**

The case described in this paper is based on the principles of CDIO (Crawley, Malmqvist, Ostlund & Brodeur, 2007) in relation to the teaching and learning of engineering students. The main idea behind the CDIO initiative is to present a framework for preparing engineering students for their professional role and by providing all necessary skills not only within the disciplinary area, but also generic skills. The generic skills are needed for working within development of products and service as well as for a lifecycle thinking. Crawley, Malmqvist, Ostlund & Brodeur (2007, p. 1), state that the “CDIO approach builds on stakeholder input to identify the learning needs of the students in a program, and construct a sequence of integrated learning experiences to meet those needs”. The stakeholder input and real-life scenarios needed for a true CDIO approach to education have made the use of different types of project based learning increasingly common within engineering education (Mills & Treagust, 2003). This is mainly because of its ability to include both disciplinary and generic skills in a setting similar to the student's future professional role. The case illustrated in this article seeks to respond to the need to give students skills within the CDIO Syllabus 2.0 regarding Interpersonal skills: Teamwork and Communication.
The paper is based on an action based research approach implementing changes in two courses on the Master of Science in Interaction Technology and Design study program at Umeå University. The courses are “Project management” (7.5 ECTS) at the department of Applied Physics and Electronics and the disciplinary course “Interactivity in smart environments” (7.5 ECTS) at the Department of Computing Science. Both of these courses are project-based (Krajcik & Blumenfeld, 2006), meaning that theory are taught in parallel with a project teaching and testing students ability to apply their skills. The courses are given in parallel during late fall parallel on 50% study pace. The implementation is based on using the project on the course “Interactivity in smart environments” as the basis of the course “Project management”. This was a modification compared to previous years when a “fake project” without disciplinary connection had been used on the Project management course. The pedagogical project of combining the two courses aims towards providing results and learning outcomes connected to the CDIO standard 1 (Context), Standard 2 (Learning outcomes), Standard 3 (Integrated curriculum), Standard 5 (Design-implement experiences), Standard 8 (Active learning) and Standard 11 (Learning assessment). The students involved are all studying the Interaction Technology and Design Study Program at Umeå University. This is a five-year integrated cross-disciplinary Master of Science study program in media technology, interaction technology and interaction design. The entire program is firmly rooted in the CDIO approach with courses covering the central and important aspects of all four parts of the CDIO Syllabus as well as the CDIO Standards. Therefore, in addition to basic and standard engineering courses, the program have courses covering areas like business strategy and value creation, prototyping, development and testing along with using and operating systems as well as project management.

This paper reports a case study (e.g. Stake, 2005; Yin, 1994) of changes made during fall 2016 by integrating and making a touch-point between two different courses on a five-year integrated Master of Science program at Umeå University, Sweden. Since the authors were part of the actual changes studies, the used research approach is action based, implementing changes to two courses and studying the effect on the students. The data collection for this study has been done during late fall 2016 and early spring 2017 and with students and teachers involved in the two courses affected of the changes made. Furthermore, surveys have been done with students not involved in the changes. Data have been collected as both anonymous surveys (Fowler, 2014) spread out during the course and by auscultations and group interviews (Fontana & Frey, 2005) during students' meetings in the course “Project management”. All participation, in any of these data collection sessions, have been voluntarily by the students and to minimize the bias in the surveys, the students were not informed about the use of the data in research beforehand (Aleamoni & Hexner, 1980).

This paper is based on a single case study design of a unique case (Yin, 1994) and this paper is written in line with the ideas of Stake (2005, p. 460), that states “the purpose of a case report is not to represent the world, but to represent the case”. Hence, even though using a case study based methodology has certain limitations when it comes to generalization, it is a suitable method for documenting this project since this paper aims to give insights into the change of education in line with the CDIO principles.

RESULTS AND DISCUSSION

To successfully learn engineering, projects are an important part to acquire the knowledge necessary. The foundation of CDIO is based on visions for engineering education that
closely connect to the need of teaching the students project management – e.g. “Rich with student design-build-test projects” and “Integrating learning of professional skills such as teamwork and communication” (CDIO, n.d.). To work according to the CDIO Standards, most of the engineering students at Umeå University study the course Project management which is based on both theoretical assignments and a group project. The purpose of the group project is to give the students both experience from and letting the students take part of a project. Thus, the philosophy and aim is “learning project management by doing a project” to facilitate collaborative learning (cf. Turner & Paris, 1995).

BACKGROUND AND IMPLEMENTATION

This pedagogical project started during spring 2014, when evaluations of the course Project management had, for a while, indicated that the students had little motivation to perform during the Project management course. Using students to evaluate the course longitudinal in cooperation with the Program director found that the main reason for the low motivation among students was the project part of course. Hence, the motivation during the course dropped when this part had to be performed. Furthermore, previous evaluations also indicated that the lack of meaning of the projects was one of the major factors that lowered the motivation during the course. Most of the projects the students had to implement were “fake” projects with no real meaning or significance to the students, e.g. to make a baking instruction video, and plan for a public movie night at the University or a ski trip to the Alps.

The pedagogical project described in this paper was initiated to increase and maintain the motivation while studying Project management. The students at the Interaction Technology and Design study program are studying “Project management” in parallel with the disciplinary course “Interactivity in smart environments”. This course has a similar structure as Project management, but is disciplinary and the project is used to let the students apply their skills in a real situation. Thus, the students do carry out two projects on two different courses at the same time with no interaction – one with disciplinary meaning and no real project management structure and one general project with high level of structure in project management (Figure 1). In fall 2016 the two courses, described above, were combined and given a touch-point in having the same project for both courses (Figure 2). The overall aims were to (1) maintain the motivation among the project management students while carrying out the project, (2) providing a better formal project management structure to support the disciplinary course, and (3) give the students more time for disciplinary project work.

![Figure 1. Traditional course structure: Two courses in parallel, no interaction.](image-url)
Both interviews and online questionnaires were used to assess the effects on the students from the new possibility to conduct a shared project, between the courses. The questionnaires were sent to the students at the start of the courses and at the end (after the final exam). The response rate of the first questionnaire was 66% (19 out of 29) and the second questionnaire was answered by 79% (23 out of 29).

**Maintaining motivation**

The first aim was to maintain the motivation on the project management course during the implementation of the project work. The results of the questions which were identical in the first and second questionnaire can be seen in Figure 3. The presented results are the mean values of answers on a Likert scale ranging from 1 to 5. It can be seen that the average value of the motivation during the course was equally high (3.7) both at the start and at the end of the course, i.e. no drop in motivation for the course Project management can be seen in Figure 3. However, a slight downward tendency during the progress of the course can be noticed in the motivation specifically connected to the interlinking of courses, (3.9 versus 3.3). Students commented this as: “Regarding the parts in project management, the motivation have been relatively high”, “Had high motivation in the beginning but became less with time” and “The motivation has gone up and down”. According to the students, this declining motivation could primarily be explained by unclear instructions and lack of feedback from the disciplinary course, which increased the students’ confusion about the goals. This will be further discussed later.

![Figure 3. Summary of results from questionnaires sent to students studying the course Project Management.](image-url)
Another reason for the slight decrease in motivation due to the combination of the two courses could have been that the students had very high expectations on the success of this course combination. This was measured in the questionnaire with the question: “Combining these two courses will make the course project management more interesting?” The result was an average agreement of 4.6. Such a high value is hard to improve. In that case, a more reasonable question becomes: How much of these high expectations will be fulfilled during the course? The overall motivational levels during the course shown in Figure 3 are taken to be that, to a large extent, this was fairly successful.

**Better formal project structure**

The second aim was to achieve a better formal project management structure to support the disciplinary course, i.e. Interactivity in smart environment. As described earlier, the main idea of the course Project management is to let the students produce all material necessary for managing a project while performing a project. Consequently, by integrating the two courses, the project on the course Interactivity in smart environments will have all necessary and formal project management structure. Hence, the goal of providing a better project management structure will be fulfilled as long as the students will continue and finish both courses, which was the case. However, there are other aspects of the results that are worth mentioning.

The results further show that by giving the students the task of setting up a formal project organization, makes specification, feedback and communication both in-between involved teachers and with students to become increasingly important. As mentioned above, unclear instructions and lack of feedback on the disciplinary course and communication between teachers on the two courses increased the confusion during the project work. This was commented by one student as: "Much time was spent on discussing what the demands of the course were and how we would solve them. The requirements [from the teachers] were very unclear and the discussions took up a lot of time". Thus, even though a formal project management structure was achieved, it is important that all involved teacher can support the process.

**Spending more time on project work**

The third goal of the project was to give the students more time for disciplinary project work. According to the syllabus of Interactivity in smart environments, the project part should account for 40% of the course (3 ECTS out of 7.5 ECTS). The results show that the student groups involved in this project have, on average, spent 105 h/student on project work (according to the self-evaluation of their project plans). Assuming that the students are working full time, equal to 40h/week (200h/7.5 ECTS), the average time spent on project work is 53%. However, experience show that most students do not spend full time studying, even though this is assumed here, making this figure probably a bit higher in reality.

Measuring the same results on the Project management course, a reference group was used that followed the old syllabus performing a “fake” project (as described above). In this case the results also show a noticeable difference in the time spent on the project work. The students involved in the pedagogical project spent, on average, 105 h/student and the students in the control group spent 43.5h. Thus, the results show that combining the two courses increased the time the students could, and was willing to, spend on working with the project.
Motivation and theoretical results

The Project management course ends with a written examination focused on theoretical parts of project management. Analyzing the score from the written examination between students conducting the disciplinary project versus those conducting a non-disciplinary project, it is possible to notice a significant difference in mean score (Table 1) between students with similar background within ICT/CS education (27.8 vs 22.2). However, performing an analysis of the results from three previous years (2012, 2014 and 2015) when all students performed a non-disciplinary project, the same difference can be noticed between the different student groups. Hence, the results illustrated earlier, i.e. that a disciplinary project make the students maintain their motivation during the project (and the course), do not reflect upon the results on the written theoretical examination.

Table 1. Average score on written examination 2016.

<table>
<thead>
<tr>
<th>MSc Interaction Technology and Design</th>
<th>MSc Computing Science</th>
<th>All other students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disciplinary project</td>
<td>Non-disciplinary project</td>
<td>Non-disciplinary project</td>
</tr>
<tr>
<td>Number of students*</td>
<td>31</td>
<td>15</td>
</tr>
<tr>
<td>Mean score on written exam</td>
<td>27.8</td>
<td>22.2</td>
</tr>
</tbody>
</table>

* All students turning in blank or scoring 0 points have been excluded

Increased student engagement based on CDIO

In general, the students were happy with the changes and it is shown that not only was the aims of the pedagogical project met, but also made the students address the core of CDIO approach. The students made comments such as: “To get a grasp of working with a multi-disciplinary cooperation and to get insights from different perspectives” and “It was fun that the project, which was carried out during this course, was a ‘real’ project with an external client, etc. I also believe that we had more time compared to performing two different projects in parallel”.

Furthermore, the results show that this pedagogical project has given positive results based on several of the CDIO Standards regarding the curriculum. CDIO standard 1 (Context) by giving the students possibility to conceive, design and implement during a project based on a context closer to their future profession, Standard 2 (Learning outcomes) by letting the students gain personal and interpersonal skills in relation to disciplinary knowledge, which is important for maintaining high motivation, Standard 3 (Integrated curriculum) by integrating a course providing personal and interpersonal skills with a disciplinary course to create a more “real” scenario, Standard 5 (Design-implement experiences) by giving the students possibility to design and implement during a project on advanced level, Standard 8 (Active learning) by students in a structured manner, based on project management principles, applying knowledge, analyzing and evaluating ideas and Standard 11 (Learning assessment) by students presenting results and skills both in group and individually.

One question that arises when analyzing the data is: To what extent do the student’s initial ambition and motivation influences the results? It is far stretched to say that the results for this investigation are generalizable, but there are indications that the motivation could be maintained by integrating the same project work in the two courses. It is, however, important
to have an overall education program structure that continuously support student's motivation to take responsibility of their learning process. In addition, to give the students opportunities to integrate different skills needed for their future profession in disciplinary courses cannot be stressed enough, i.e. a more Integrated Curriculum (CDIO Standard 3). The results further indicate that just integrating skills during a few courses might give the students a feeling of confusion regarding the courses and project work, since this is not the norm. Putting the norm among the students that working with integrated projects connected to all parts of CDIO more often would, not only, prepare the students for their future career, but also raise the bar of the responsibility among the students for their learning. However, challenges arise when students pose higher demands on teachers to give timely feedback, provide knowledge and to have a holistic view of the project and integration among different courses.

CONCLUSIONS

The students had very high expectations on the success of combining the two courses and performing one shared project. The results from this pedagogical project show that the end result was successful both in terms of student satisfaction and also based on several of the CDIO Standards regarding the curriculum. Furthermore, the students maintained their motivation during the project work which historically had been a major problem with the Project management course. The students also could, and were willing to, spend more time on implementing the project. In addition, the formal structure of the disciplinary course was strengthen by implementing all formal project documentation.

Nevertheless, even though it seems like the students in general would like to keep this new structure of combining Project management with a disciplinary course, there were some associated drawbacks. The most noticeable problem was the confusion that developed among the students due to different requirements when two courses from two different department at the University were combined. Thus, for a successful continuation of this structure, a high level of communication and a holistic view among all teachers involved are desirable. Additionally, an overall structure that would continuously support, on several courses, the students' motivation to take responsibility of their learning process and give the students' opportunities to integrate different skills needed for their future profession is important. This would be possible to achieve with a more integrated curriculum on a study program level and may increase the success of integration between individual courses.

ACKNOWLEDGEMENT

The authors would like to thank all students at the engineering education programs that have taken part of the course Project management at Umeå University during fall 2016. Moreover, the students at the Master of Science in Interaction Technology and Design study program should, in particular, be acknowledged for the willingness to participate in creating integrated education built upon the philosophy of CDIO and all generic skill needed for their future career as engineers.
REFERENCES


**BIOGRAPHICAL INFORMATION**

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**Jimmy Vesterberg** is a University lecturer in Energy and Building Technology. He holds a PhD in Energy Engineering from Umeå University, Sweden. He has extensive work experience from academia as well as from the industry and a great interest in students’ learning process. His research is primarily focused on questions related to sustainable building renovation. He has been published in e.g. *Energy and Buildings* and *Journal of Building Performance Simulation* and has presented at numerous international conferences e.g. REHVA World Congress and Nordic Symposium on Building Physics.

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WAYS FOR IMPROVING THE TRAINING QUALITY OF CIVIL ENGINEERING IN DEVELOPING COUNTRIES

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ABSTRACT

Training quality civil engineers in developing countries is not an easy task given the economic conditions and tight budget for lab activities or on-the-job internships. This situation has been a headache to educators in Vietnam for decades. In order to partially mend this problem, for years, the Ministry of Education & Training of Vietnam imposed fix quotas for the number of Civil Engineering students recruited by each school each year. This is no longer effective now when most universities and colleges in Vietnam have moved from the cohort system to the credit-hour system, and students are free to transfer from one major to another. Using the case study at Duy Tan University in Vietnam, this paper argues that by adopting a series of computer and real-world simulations, the training quality problem for Civil Engineering students can be solved to a significant degree. In effect, at the freshman and sophomore levels, students may practice their lab work and experiments on construction mock-up models and/or construction simulation kits in order to learn how to apply theoretical knowledge in reality such as building concrete blocks, retaining walls, designing truss bridges, etc. From the junior level on, computer simulations will be largely used to teach scenarios and/or phenomena which may not be experimentally reproduced like structural collapse, building explosion, earthquake, etc. The main advantage here is that numerical and computing simulations help students arrive at their learning outcomes much faster while they do not cost that much. As for the senior project and internship, it has been realized that many construction companies or construction consulting firms did not provide students with the complete learning experiences needed during their internship. By creating a simulated settings for the senior projects with students and staff members playing different mock roles besides the actual project being carried out in the actual internship, students can greatly improve on their learning curve for industrial skills and knowledge. While this method does run certain academic and industrial risks, quantitative proofs from our survey have shown improved results in the skill-building process of our students besides their improved level of satisfaction for the complete training process.

KEYWORDS

CDIO Standard 3, 5, 6, Civil Engineering, internship, computer simulation, construction mock-up models
INTRODUCTION

Civil Engineering as one of the oldest engineering tracks is a broad discipline that incorporates many different tracks of other engineering and scientific knowledge, including structural design, fluid dynamics, soil mechanics, etc. These together with an increasing number of mandatory practices and strict regulations in the Civil Engineering industry today have put more pressure on Civil Engineering educators around the world to deliver the best quality education possible for their students. In 2007, under the guidance of the CDIO Framework, Guangjing set up a design-directed curriculum model for Civil Engineering in which students would be able to learn from a board array of various engineering disciplines to support their work in Civil Engineering projects while being trained on their interpersonal skills and project-management knowledge at the same time (Guangjing, 2007). Then, in 2009, Vigild and other educators at the Denmark Technology University proposed the creation of design-build projects for Civil Engineering and Architecture programs (Vigild, 2009). And yet in 2011, Krogsbøll came up with four different models of CDIO-based projects for Civil Engineering programs (Krogsbøll, 2011).

These above CDIO-based models for teaching and learning in Civil Engineering while being very effective in enhancing the quality of both theoretical and practical training are generally only suitable for small-sized classes. It is increasingly more difficult to carry out these project models in Vietnam, where the class size is usually from at least 50 students or more. The amounts of time and money needed to run experiments and to build prototypes in every Civil Engineering course are simply over the current capability of every university in Vietnam. As in the case of the Faculty of Civil Engineering at Duy Tan University, we can only carry out CDIO-based project models in a few courses. In order to overcome this reality and increase the number of courses with CDIO-based projects in Civil Engineering, the faculty members in Civil Engineering at Duy Tan University have realized that by taking advantage of computer simulations as well as simulated settings resembling real-world situations, it will become very feasible and cost effective to create a quality CDIO learning environment. Students will arrive at the expected learning outcomes even much faster while requiring less lab space and materials. A series of case studies for CDIO project courses from the sophomore to junior to senior levels at Duy Tan University will provide a good description of how this can be done and why we should make more use of computer and real-world simulations in the field of Civil Engineering for our CDIO deployment.

CDIO PROJECTS IN CIVIL ENGINEERING UTILIZING SIMULATION TOOLS AT DTU

Our CDIO projects in Civil Engineering at the sophomore, junior and senior levels all focus on dealing with some natural problems or disasters in Vietnam, namely floods, hurricanes, landslides and earthquake. The projects are all set up on building blocks of knowledge from other courses with clear parameters and requirements at the sophomore and junior levels and open-ended needs at the senior level. The learning outcomes of these projects are also well-defined and frequently reviewed by the Board of Science of the Faculty of Civil Engineering.

Carton-Paper Retaining Wall Project

This CDIO project is at the sophomore level with the aim to test students’ knowledge and skills in surveying, hydraulics, statics, and soil mechanics as well as to examine students’ ability to integrate and apply such skills and knowledge into reality. Usually, students will
need to do surveying on characteristics of the slope; to examine the erosion rate of fluid flows on such slope, taking into account the permeability coefficient; and ultimately, to calculate the bearing capacity of the retaining wall being made of carton paper.

In the first place, it is important to ask students to manually do the above calculations so that they will not easily forget the lesson in the future. However, if students have to continue to do these manual calculations after the first time as they try to revise their retaining wall model to make it better, they simply will have to spend so much time repeating the same work. Using the manual approach, at most, students can only revise their retaining wall model twice in this CDIO project. Instead, by using either FIDES-GeoStability or Plaxis software to build up the simulated model of the retaining wall on computer, students can test the bearing capacity of their wall in so many different scenarios from landslide to flood to fluctuating levels of soil moisture, etc. simply by only a few mouse clicks to change the testing parameters. The use of simulation software in this CDIO project during the last semester basically had changed the learning outcome of this course from building a retaining wall model and calculating its bearing capacity to building a retaining wall model with the optimal bearing capacity. The subsequent actual test of the retaining wall models made from carton paper also became more of a heated competition between the students since they now had all the necessary tools to refine their prototypes any time.

Figure 1. Retaining wall model simulations by FIDES-GeoStability (KEA)

Figure 2. Test of retaining wall models made from carton paper
O-Thuoc Bridge Design Project

This CDIO project is at the junior level, and its purpose is to test students’ knowledge about structural analysis and design as well as about strength of various materials. Two major tasks for students in this project are (1) to formulate a structural design for a bridge with a specified span length, and (2) to choose the material which will optimize the loading strength of their bridge design.

More than often, students would refer to some bridge design already available from the Internet or from friends who already took the class before, and then tried to improve on that design. This was a wrong approach right from the first place because students did not get to try out the designs of their own and/or learn from their mistakes. In turn, that already-available bridge design also predetermined their choice of material to a great extent. In fact, at the end of the project, when we asked why they chose certain material for their bridge design, very few could respond well to that. Moreover, many students mistook the real purpose behind our competition of their bridge designs made out of chopsticks. Many actually tried to win the competition by optimizing their design for the material being used, which is bamboo wood or lumber without recognizing the fact that it was used to relatively compare one bridge design to another in a public competition since we could not have had them make the real bridges. Indeed, questions about their understanding of structural analysis and material strength or mechanics around their own bridge design were really how we tried to evaluate their projects. As a result, as we introduced SAP2000 and Etab to this CDIO project, students’ mindset and approach was totally changed. Students can now model any structural design of their bridge on computer, and test out the ratio between the bridge weight to the maximum loading weight the bridge can sustain using any type of material, be it wood or iron or steel or some composite. The computer simulation also helps students cut down on their time and effort for making the bridge prototype: usually, they needed to make 3 to 5 bridge models to arrive at a satisfactory one for the competition; now, they only need to make 1 to at most 2 models. The learning outcomes of this CDIO project course indeed have been re-emphasized in a much clearer manner to our students through the use of computer simulations.

Figure 3. Modeling of a bridge design by SAP2000 software
Earthquake-Resistant Building Project

This CDIO project is at the senior level and has the goal of assessing students’ application and integration of knowledge from different Civil Engineering sub-fields of structural dynamics, structural analysis, strength of materials, skyscraper design, etc. The project prototype here is supposed to be the design model of a tall building so that it can be tested against earthquake of different magnitudes and intensity.

Unlike previously mentioned projects, it is hard to assess with absolute accuracy whether one design is better than another through some systematic calculations here because earthquake can always occurs differently from one place to another as well as from one time to another in the same place. The only reliable way to assess the strength of a building in event of an earthquake is to test its design in some computer simulation or on an earthquake simulated machine. As a result, the Faculty of Civil Engineering at Duy Tan University has
adopted the complete evaluation criteria set of the international IDEERS competition (Introducing and Demonstrating Earthquake Engineering Research in Schools) in Taiwan for this CDIO project class. Unfortunately, we do not have enough funding to acquire a simulated earthquake machine which is worth hundreds of thousand dollars; as a result, we had move to adopt the Cast3M software for this project. The good thing about the Cast3M software is that it helps identify the locations of cracks caused by earthquake on building structures and through those, it will be able to identify which aspects the structural design of a building is weak on in event of an earthquake. Because of this software, our students now learn more about the nature of earthquake at different magnitudes rather than just focusing on making strong structural models to stand the test of theoretically-simulated earthquake only. In fact, by examining the cracks on walls of houses in the earthquake at Song Tranh, Tra My, Vietnam in 2013, our students and their mentors have been able to reconstruct the simulated earthquake of the time on computer and also published a scientific paper about how houses in Song Tranh should be built to avoid such damages next time some earthquake hits again.

![Figure 6. Cracks found on the walls of houses at Song Tranh, Tra My, Vietnam after the earthquake of 5.1 Richter in May 2013](image)

![Figure 7. Modelling of typical walls under effect of an earthquake, with (a) and without (b) reinforced concrete lintels. Yellow zones indicate locations of the compressive stresses.](image)

**Simulated Construction Project Management Work**

A recent study of our students’ internship experiences at local construction companies and construction consulting firms has revealed that many of our students did not receive a
complete set of training on essential skills and specialties. The overloading number of interns at many companies has driven down the quality of most internships. While it is possible to set up joint internship programs which are structured to include both our university mentors and corporate personnel in addition to clearly-defined learning outcomes for the students, not every company welcomes the idea either because they are too busy or because they simply do not have the resource to run such programs given their conditions in Vietnam. To make it up for this, the Faculty of Civil Engineering at Duy Tan University has recently borrowed from the idea of simulated case studies of our Medical School, in which we hired people to act as if they were having a certain illness profile and our medical students would practice interviewing and consulting for these “faked” patients. Applying the same doctrine and approach, during the last semester, our Faculty of Civil Engineering has set up a series of case studies in which our mentors were playing the roles of clients, architects, construction quality-assurance personnel, construction project managers, construction consultants in various fields, etc. to get students involved in simulated scenarios, in which they need to practice their skills for negotiation, documentation, problem-solving, and decision-making. While this effort was hailed for its novelty, in a number of situations, when students tried to adopt unfamiliar practice or approach, our mentors were not able to provide then with accurate or satisfactory evaluations because they had not been trained well enough for this new effort. In addition, right now, most of the simulated settings are only for short case studies rather than for some complete projects; as a result, some faculty members have become concerned that not all of the related skills and know-how needed for a specific case study are well-integrated into these classes, and it would be hard for our students to learn from discrete pieces of clues and tricks. This is not to mention of the fact that not all of our mentors have real-world experiences, and their acting may not resemble what actually is happening in the construction industry in Vietnam.

SURVEY & DISCUSSION

In order to verify the validity and relevance of our efforts to embed computer and real-world simulations into our CDIO project courses, it is important to assess students’ performance and perception of the new approach. As a result, we have prepared a survey, focusing on identifying students’ perceived improvements in the following areas:

- Problem-solving
- Knowledge discovery
- System thinking
- Personal skills
- Professional skills
- Teamwork skills

A Likert rating scale of 1 to 5 was adopted for the survey with 1 for Strong Disagree, 2 for Disagree, 3 for Neutral, 4 for Agree, and 5 for Strongly Agree. The survey is expected to help find significant improvements in some of these above performance and skillset areas.
<table>
<thead>
<tr>
<th>No.</th>
<th>Problem Solving</th>
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<th>5</th>
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<tbody>
<tr>
<td>1</td>
<td>The simulations call for additional brainstorming time between team members before arriving at the end outcomes.</td>
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<td>2</td>
<td>The simulations help me ask the right question and identify the right problem at any point in the project.</td>
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<td>3</td>
<td>The simulations help me identify the relationship between various problems in the project.</td>
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<td>4</td>
<td>The simulations require me and my team to follow through some development model or life cycle to carry out a specified CDIO project.</td>
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<td>5</td>
<td>I have a better grade on my CDIO project due to the support of simulations.</td>
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<th>No.</th>
<th>Knowledge Discovery</th>
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<td>6</td>
<td>Through simulations, I have developed better knowledge in Statics, Dynamics and Mechanics.</td>
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<td>7</td>
<td>Through simulations, I have developed better knowledge in Structural Analysis and Design.</td>
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<td>8</td>
<td>Through simulations, I have developed better knowledge in real-world construction technologies and practices.</td>
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<td>9</td>
<td>Through simulations, I have developed better knowledge in Construction Project Management.</td>
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<th>No.</th>
<th>Systematic Thinking</th>
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<tr>
<td>10</td>
<td>The simulations help me identify problems based current constraints and potentials.</td>
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<td>11</td>
<td>The simulations help me immediately identify the inputs and outputs for any problem or process emerged in the project.</td>
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<td>12</td>
<td>The simulations help me envision problems that may emerge from current solutions of the project.</td>
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<tr>
<td>13</td>
<td>The simulations help me better integrate knowledge from different fields of Statics, Dynamics, Hydraulics, Structural Analysis, Strength of Materials, Soil Mechanics, Construction Practices, Project Management, etc. in my thinking.</td>
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<tr>
<th>No.</th>
<th>Personal Skills</th>
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<tr>
<td>14</td>
<td>I feel calm and confident working on CDIO projects with the support of computer simulations.</td>
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<td>15</td>
<td>The simulations help me become efficient in my CDIO project work.</td>
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<td>16</td>
<td>The simulations help me become accurate and productive in my CDIO project work.</td>
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<td>17</td>
<td>The simulations help me become innovative in my CDIO project work.</td>
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<td>18</td>
<td>I do feel as though I have to be too dependent on the support of simulations.</td>
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If I make a mistake in my work, I can always go back and change the parameters in my simulation to make it right.

The simulations make me feel enjoying the work of a Civil Engineer.

<table>
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<tr>
<th>No.</th>
<th>Professional Skills</th>
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<tr>
<td>21</td>
<td>My communication teams improve to a great extent as a result of the new CDIO project settings.</td>
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<td>22</td>
<td>Working with simulations in the projects require me to better manage my time.</td>
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<td>23</td>
<td>Various parameters in the simulations provide me with a clearer list of resources needed for the project, and as a result, I found it easier to identify and coordinate resources for certain work.</td>
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<td>24</td>
<td>The simulations allow me to become more flexible in my project work, and help relieve me of great amount of stress compared to before.</td>
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<th>No.</th>
<th>Teamwork Skills</th>
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<tr>
<td>25</td>
<td>Simulations help us learn more about negotiation and communication skills.</td>
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<td>26</td>
<td>Simulations help us resolve team conflicts quicker and easier.</td>
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<td>27</td>
<td>I did do coaching and received coaching from other team members in the settings of the new simulations for our CDIO projects.</td>
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<td>28</td>
<td>I would not mind managing a team in a project if given the responsibility.</td>
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<td>29</td>
<td>If the team cannot work out the solution together, each member can work on simulation independently to arrive at effective results.</td>
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Preliminary feedbacks from our students have shown a surge in the interest for the use of computer and real-world simulations in CDIO projects in Civil Engineering at Duy Tan University. We have carried out the survey on 112 students of the civil engineering programs and the results are shown in Figure 8.

Figure 8. Survey result of DTU students about the improvements after simulation implements
The result shows that three groups of System thinking, Personal skills and Professional skills got the improvements, except that at Question 17 - *The simulations help me become innovative in my CDIO project work?* At this aspect, we can see that the simulation sometimes might destroy the innovative ideas. The averages of other groups are around level 3 (Neutral) which shows the simulations not help students to improve the Problem-solving, Knowledge discovery and Teamwork skills.

**CONCLUSION**

While there is more to discuss about the use of computer and real-world simulations in CDIO projects in Civil Engineering at Duy Tan University, one clear benefit for certain up to this point is that the approach helps save great amounts of time, money and other resources on the part of our Faculty of Civil Engineering. In addition, students appear to have better experiences with the Conceive and Design phases in their CDIO projects besides better understanding of the learning outcomes behind each project which lead to the improvements of System thinking, Personal skills and Professional skills. The new approach also requires more preparation efforts on the part of the Civil Engineering faculty members; however, those who completed their preparation work turned out to have easier time handling the class and monitoring their students’ work. This actually brought about greater time for evaluation and feedbacks, which is a strong improvement in terms of our training quality.

**REFERENCES**


BIOGRAPHICAL INFORMATION

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Minh Chau Duong, M.Eng. is lecturer of Civil engineering faculty, Duy Tan University. His research areas are highway design, traffic engineering. His current scholarly activities focus on the implementation of CDIO to the Civil Engineering programs at Duy Tan University.

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LEARNING THROUGH THE HANDS-ON PROJECT: 
AN INTRODUCTION TO THE FRESHMAN ENGINEERING PROGRAM

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Chuang-Chien Chiu
Department of Automatic Control Engineering, Feng Chia University

Wei Wang
Department of Economics, Feng Chia University

ABSTRACT

Feng Chia University regularly improves its teaching quality and standards based on student learning outcomes. Improvements have been made in the areas of curriculum planning and management mechanisms in accordance with the needs of relevant industries and students. Through the “conceive, design, implement, operate (CDIO)” educational model, Feng Chia University has innovated its methods of teaching and course design to increase students’ interest and motivation while cultivating their interpersonal communications and problem solving capabilities. In addition, FCU works to gain international accreditation so as to bring curricula and educational quality in line with international standards and benchmarks.

This study introduced different kinds of “hands-on” projects for freshman in the Department of Automatic Control Engineering and the Department of Urban Planning and Spatial Information at Feng Chia University in Taiwan. Students and faculty of these two departments have formed inter-discipline research teams. The teams have adopted the CDIO model to design Freshman Project, focusing on the themes of “Smart City” and “Smart life.” The projects require students to brainstorm and integrate their knowledge. Moreover, integrating project-based learning and CDIO educational model has enabled students to experience the Conceive-Design-Implement-Operate process while brainstorming above two issues. In this paper, the freshman project consists of three main parts: a series of lectures and seminars, hands-on project, and a group presentation or competition, in order to develop personal, interpersonal, and problem-solving skills.
KEYWORDS

CDIO approach, hands-on project, Introduction to engineering courses, Standards 4

INTRODUCTION

In view of the shift towards low fertility and aging populations, talent acquisition represents a nation’s future competitiveness. Thus, training competitive talent to develop a global vision, as well as multicultural qualities, and the ability to combine theory and application, is the main consideration of higher education in the future. Furthermore, in order to train talent to fulfill adequately the demands of different sectors amid the development and transformation of industries, both the quality and quantity of talent must be enlarged as well. Therefore, the methods for educating future talent are particularly important.

In this information age, the amount of information can be easily accessed online and university is not the only source for knowledge innovation and cultural explanation. Therefore, it is urgent for university to rethink the role and functions of higher education in order to help students become global citizens.

However, a remarkably huge gap between higher education curriculum and industrial needs in Taiwan has led to dilemma and challenges for teaching and learning in engineering education. Therefore, offering curriculum for engineering students to understand aspects of conceiving, designing, implementing and operating systems for international competitiveness has become an urgent issue to discuss in university engineering education.

Education transition is a continuing activity in all engineering education to meet future technological needs (Lehmann, Christensen, Du, & Thrane, 2008). Therefore, in the academic year of 2016, Feng Chia University launched a freshman project for every first-year students, aimed at inspiring his/her imagination, creative thinking skills, and soft skills. The project made use of theme-based learning activities targeting vital employment skills in various professional fields. Students thus have the opportunity to realize their future professional sectors, and experience different learning methods to those previously experienced in senior high schools.

This article illustrates the execution of the freshman project at Feng Chia University. The goal of the program is that, through simple project-based practical learning, students develop an understanding of the learning themes and content within their department, as well as learning to recognize how to distinguish vitally important “gaps” in knowledge needed in their future study. Moreover, it was hoped that by increasing students’ learning motivation and interest, the study methods would be transformed, and the goal of training innovative talent can be achieved.

THE WAY OF PLANNING THE FRESHMAN PROJECT AT FCU

The Center of Teaching and Learning Resources (CTLR) is responsible for the design of the freshman project at Feng Chia University. In addition, a teacher’s research community was organized to facilitate teachers’ unified understanding of the project through interaction, discussion, and peer learning. Also, FCU organized a day referred to as “The Day of Learning Together,” with the purpose of breaking down barriers for planning classes across disciplines, as well as increasing the opportunities for students to develop in a multidisciplinary learning environment. It was therefore decided that FCU would allocate a
common available timeslot across all departments and faculties, which is to remain empty, with no departmental classes during the slot. This arrangement allows students and instructors have the opportunity to plan time for discussions and lectures according to their learning and teaching requirements in the project-based learning program.

The implementation of the freshman project can be divided into two categories: (1) intensive course: courses that are held five to ten days prior to the beginning of the semester intensively; (2) course throughout the semester: a six to eight-week course held on each “Day of Learning Together.”

The freshman project is comprised of diverse members, including the course instructor, experts from industrial fields, teaching assistants, and students in their second year of study or above. By using a combination of real-world examples within the industry, and challenges faced in the 21st century, students work in teams throughout the program. At the end of the course, students present their results in various ways, such as written reports, oral presentations, product development, videos, drama performances, contests and so on.

THE CURRICULUM DESIGN OF DEPARTMENT OF AUTOMATIC CONTROL ENGINEERING

This course was divided into three main themes, including self-propelled vehicles, graphene sensors and dye sensitized solar cells. On the first day, teachers introduced the principles and applications of a variety of basic sensors in an oratory manner, followed by introducing the revolutionary material, graphene, and finally is the green energy components. Beginning with the introduction of sensors, graphene and solar cells, teachers summarized application fields with great future potential, leading to the current mainstream industrial sensing method, and the introduction of graphene-related commercialization technology. The second day courses centered on the implementation of the self-propelled vehicles and dye sensitized solar cells, respectively, with the former including design and assembly, where students had to implement vehicle design and creative modification. The course of dye sensitized solar cells required students to try different kinds of dye and observe their performances. The afternoon course content included self-propelled vehicle racing, exterior display, and performance competition, as shown in Figure 1.
Based on the three main purposes of freshman project: “imagination is infinite”, “value is infinite” and “contributions to human environment is infinite”, creative subjects could be self-defined for discussed by each team. Important issues of current social demands or yet-to-breakthrough science and technology issues could be selected as the discussion subjects by teachers. Additionally, at the end of the course, innovative prototypes pertaining to the defined subjects were presented via the teaching aids of self-propelled vehicles and solar cells, which marked the most important event.

For self-propelled vehicles, including sensing circuit and motor control circuit design, teachers developed and examine students’ circuit design ability and practical welding operation skills; for green energy components and two-dimensional material, including integration of solar cells and emerging material of graphene, teachers enabled students to acquire knowledge on energy, and strengthened their exploration of different science fields. In addition to teaching fundamental circuit and control theory, the teachers also developed and examined students’ knowledge on basic electrical science and control, as well as their active cooperation and diligent study attitude through teamwork among students. In addition, teachers also examined the attitude of teamwork and the degree of knowledge absorption via group discussions, and finally surveyed the students’ vehicle tuning and practical operation skills through subject competitions on self-propelled vehicles, including individual competition, team relay competition, and external rating, where the self-propelled vehicle-based team relay competition was used as a criterion to examine the effectiveness of students’ giving play to their creativity, triggering their learning interest, teamwork spirit and learning attitude.

Taking advantage of the freshman-training period, the department of automatic control engineering required students to perform freshman projects, where the students were grouped to develop teamwork spirit. Meanwhile, a subject-based innovative ideas course was arranged to let them brainstorm and come up with innovative and practical applications, where the prototypes of “self-propelled vehicles” and “graphene-based green energy
components” were employed to realize their innovative applications. Finally, the results were presented by each group in a performing manner. With simple operation and assembly procedures, the freshman students not only triggered their interest toward college life, but also developed the attitude of team responsibility and innovation, which is more important.

THE CURRICULUM DESIGN OF THE DEPARTMENT OF URBAN PLANNING AND SPATIAL INFORMATION

Using “Exploration of Urban Spatial Imagery” as the main topic, the freshman project for the Department of Urban Planning and Spatial Information has broken away with the core concept of communications. In the past, teaching assistants or teachers communicated with students in a unidirectional manner in the freshman training. This has been changed into a “co-curatorial” approach, where students could understand how to explore the city and construct mind maps to learn the basic concepts of urban design through paper model making and 3D printing. The event took place on September 9th-11th, 2016, and there were three teachers co-guided 110 two group-based students of this department.

Aiming at the students of the two classes in the Department of Urban Planning and Spatial Information, we granted one credit for this course, whose core purpose is to trigger student interests in Urban Spatial Imagery Design. With campus as the implementation site, the course was divided into two phases:

First Phase of This Course

The first phase aimed to construct paper models for the indispensable elements of the urban spatial imagery. First, the teachers explained the paper model making process, and illustrated the relationship and design of the structure elevation required to be investigated in drawing a paper model, which allowed students to have a clearer concept of the required details such as objects and dimensions for constructing the paper models. Next, the students were required to design the blueprint for the 3D paper building model in person to test their abilities, and to finish constructing the 3D paper models using cut and paste. In this way, the students could understand the spatial imagery components through different orientations (the relationship of objects with different facets, the importance of accurate calculations for the construction process), and through collaboration, the students finished constructing the post-exploration urban spatial environment, which was also aimed to trained the students to improve their concentration and cultivate their patience.

Second Phase of This Course

The second phase course aimed to provide the students with theoretical teaching and practical implementation guidance regarding 3D computer graphics model generation. For 3D printing, with the course provided in the first phase, the students were more familiar with the exploration of the urban spatial imagery. Next, the course was intended to enable the students to more professionally and delicately finish constructing the urban spatial imagery. First, the students were required to be familiar with the operation of computer modeling software through basic procedure, based on which and the deformation and material transformation tools, the student learned how to make spatial imagery elements. Finally, the results of spatial imagery construction were presented. In the process, the students completed finer urban spatial imagery in a manner different from the paper model approach, which made them understand the features of 3D software. Additionally, the students could
select an appropriate approach based on their requirement to construct high-quality 3D models. Finally the students were grouped to plan the urban spatial imagery they knew, and were given opportunities to present the results to more clearly convey the planned connotation.

In general, with 3D printing and the manufacturing of the paper models, the students have understood the features of the three-dimensional implementation procedures and the manufacturing skills. In addition to triggering fun for handmade models, they also brought the students closer to the problem of practical modeling design, enhancing the students’ conceiving and implementation ability, and making students better understand the components required to be considered in different aspects of spatial imagery as well as understand the spatial imagery step-by-step. Additionally, the students could learn the applications of technology in relevant fields, and complete constructing the urban spatial imagery together through the grouping method. With the models pieced together, a complete campus of FCU was constructed. Finally, the results were presented, where the students could express their opinions and imaginations concerning the exploration of urban spatial imagery after the course study. The course also connects the anchoring course and urban design of this department, serving as the prerequisite course for the anchoring course, and developing students’ basic urban design concepts and practical skills. Moreover, this course can assist two groups of students in taking the sophomore and junior-based practicum course. It is expected to diversify the practicum course as practical cases of urban design.

For improving teaching quality, a total of 3 teachers engaged in this course. They divided the courses into two phases, which allowed students to explore the urban spatial imagery with different methods and different aspects, and enabled them to express their conceived imagery. Also, the results were presented to enable the students to clearly express their opinions and imaginations concerning the exploration of urban spatial imagery after the course study.

In the promotion of research on energy, with different auxiliary materials most familiar to the students such as a variety of paper tapes, convenience stickers and paperboard, computer software and 3D printers, the course made the students understand the urban spatial imagery step-by-step, and enabled them to learn the applications of relevant field technology, and complete constructing the urban spatial imagery together through the grouping method, with the final result being a complete FCU campus model, which was constructed by piecing together all models. The course also connected the anchoring course and urban design of this department, serving as the prerequisite course for the anchoring course, and developing students’ basic urban design concepts and practical skills. Moreover, this course can assist two groups of students in taking the sophomore and junior-based practicum courses and practical cases of urban design which are expected to diversify the practicum course.

**CONCLUSION**

More and more industries have involved actively in researching industrial innovation and transformation in recent decades. Thus, it is essential for Taiwanese universities to participate in social enterprise and collaborate with industries to improve students’ abilities and knowledge to meet industrial needs. In order to enhance students’ interests in engineering education, FCU design freshman project for every freshman student in the academic year of 2016. Using active and experimental learning techniques and hands-on
activities help establish integrated curriculum to improve students’ personal and interpersonal skills and product, process and system building skills with disciplinary knowledge in those projects. Students have opportunities to directly participate in the conceiving and problem-solving process through experiencing freshman project and learning from Introduction to Engineering curriculum. The notion of this framework is to provide students opportunity to offer an outline of a project and their responsibilities of an engineer and to apply their professional knowledge into execution. Also, in recent decades, there has been an increasing need for interdisciplinary experts in various industries. Thus, it is crucial to add elements of humanities and social sciences into contemporary engineering education. Considering how to equip engineering experts with both basic engineering knowledge, improve ability for innovation and design, and design products without missing elements of art and humanity has become an important topic for engineering education in higher education.

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A PROPOSAL OF THE C-D-I-E MODEL TO IMPROVE STUDENTS’ INNOVATION CAPABILITY

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ABSTRACT

Electrical & Electronic Engineering (EEE) study and research tracks are typical from other disciplines in that they are usually fast-changing and often require a high level of innovation on the part of both the learners and teachers. With the fact that Vietnamese higher education is shifting from an elite educational system to a universal one, it has introduced even more problems to most of our EEE students who do not receive sufficient innovation learning experiences as well as to our EEE instructors who lack adequate training on how to teach their students become more creative. Over the past three years, our Faculty of Electrical Engineering has learned many tough lessons about how to effectively administer the CDIO model to promote students’ innovation capability under the current settings and conditions, and as a result, they have revised on the original CDIO model to propose the C-D-I-E model with the last new “E” letter standing for “Evaluate”. The reason behind this has to do with the fact that for most of the EEE Capstone projects, we rarely could carry out the Operate phase given the limited amount of time for each project, and instead, if we can better “Evaluate” on the level of innovation of a given project, it will provide our students with better feedbacks on how they may improve on their work now or next time. Our C-D-I-E model has yielded certain fruitful results, and in this paper, we will go through three case studies of projects adopting this model, moving from a well-structured project to an open-ended one in order to assess its level of effectiveness across the spectrum.

KEYWORDS

Conceive-Design-Implement-Evaluate (C-D-I-E) model, CDIO Framework, CDIO Standard No. 5, 8, 10, creativity evaluation/assessment, EEE (Electrical & Electronic Engineering), innovation capability

INTRODUCTION

In recent years, a major call by government officials as well as public figures in Vietnam is to turn the country into an innovation or entrepreneurial country (Adam Szirmai, 2011). At a less macro level, in higher education of Vietnam that call is to transform or create a new innovation-university model (Thomas J. Vallely, 2008). All of these were prompted from the fact that the economic reforms in the country over the years have helped accumulate enough resources for people to start thinking of making the country “soar up” like it has happened before in other Asian countries like Japan, Korea, Taiwan, Singapore, etc (Liu, 2010). For us,
as the educators of the next generations of college students of Vietnam, the task is simply to make our students become more creative in their work and to be more proactive in their lifestyle approach so as to develop better career track when they enter the labor market. Years of rigid education and strictly-controlled curricula of the communist era have “killed off” the creativity mentality and motivation in the mindset of many generations of students in Vietnam (OECD, 2002).

While the Information Technology (IT) discipline receives the most attention and publicity for the movement toward innovation and entrepreneurship, the whole IT industry of Vietnam has been mostly focusing on “outsourcing” work (John, 2004). On the other hand, quite a number of electrical and electronic products of Vietnam have earned their names or at least a “Made in Vietnam” citing for the trademarks of some foreign investors. While the nature of job opportunities in EEE may not be as sophisticated as those for IT, there are usually many more job opportunities for EEE in Vietnam. As educators from various engineering fields, we believe that if Vietnam can approach the EEE industry in a novel way and manage to integrate IT features into packaged EEE products, it will definitely achieve more stable and long-term economic success, especially in the face of prevailing conditions for commercial piracy in Vietnam. The question for us as college educators then becomes how to teach our students about innovation and what level of innovation needed to satisfy the requirements of the current EEE industry of Vietnam.

Through our deployment of the CDIO model at Duy Tan University, answers to the above questions have become clearer as we earned more experience in the process. Innovation, as defined and/or implied by most knowledge models, is simply some improvements from the status-quo in terms of quality, functionality or appearance of some products or category of products (Fei, 2013) (Wang, 2013) (Zhang, 2013). At the extreme, if such improvement means making a totally new product and/or creating a new commercial demand or lifestyle need, that can be considered as a new invention or creation (Wu, 2013). In order to help students develop their own innovation capability, we need to equip them with:

1.1. A curiosity for existing problems in life,
1.2. A thirst for knowledge about how things are functioning (let it be a product, a machine, a software, etc.),
1.3. An ability to analyze and integrate data from different sources,
1.4. A habit of life-long self-learning,
1.5. A willingness to exchange knowledge,
1.6. A motivation for making new things (be it for better or for worse).

While we may be able to equip students with most of the above, it is usually difficult to help them with either the first 1.1 or the last 1.6 items. Some students will naturally develop their curiosity for existing problems in life, and some others seem to always have a motivation for making new things. Those with both of that curiosity and motivation usually will become successful entrepreneurs later on. The CDIO model adopted over the last couple of years at Duy Tan University have gone a long way in promoting an innovation spirit, especially amongst those faculties where the learning outcomes focus on making tangible products or product prototypes. Within our student communities, the habit of knowledge exchange and innovation thinking were also promoted to great extent. However, the uneven success (or failure) of CDIO in terms of developing students’ innovation capability at different faculties has prompted university leaders to look into the reasons behind that.
C-D-I-E MODEL DESCRIPTIONS

Being one the very successful faculties at Duy Tan University in the mission of enhancing students’ innovation capability through CDIO, our Faculty of Electrical Engineering has realized that our success all comes from our meticulous evaluation of students’ performance and constant feedbacks and encouragement for their work. The reason behind this is because our students always questioned us about whether their products or product prototypes will survive the test of time or in different markets around the world, and since we did not have time to completely carry out the Operate phase for most of their projects, we would have to do better evaluation of whatever they had done. So came our C-D-I-E model.

Our Evaluate component focuses on the following major evaluation criteria:

**Novelty or Originality** (of ideas, prototypes, or products): At the core of every project, the ideas which drive the project and facilitate creation of new products or prototypes are the most important items. Even if a project may not work out successfully, its driving ideas can still earn that project the highest grade if they are considered to be completely novel and original. Evaluation of the novelty and originality of ideas, however, are usually subjective; as a result, our Faculty of Electrical Engineering had set up a CDIO Project Evaluation Board to scan through all of its CDIO projects in any given semester. Students are required to write up an overview about the ideas of their projects, what are their benefits, who will get the benefits, how much protected the product will be from other substitutes, how long the product is expected to survive in its market niche, etc. Part of the reason for these overview write-ups is to help save the time and effort of the CDIO Project Evaluation Board, who have to work on a large number of CDIO projects.
**Logical Structures** (of the project): Given the project ideas, students would need to build up a roadmap for their projects; or more specifically, they need to select a product development life cycle and set up all the details of their project around such life cycle. While we always try to encourage new ideas from our students, we also warn them not to “reinvent the wheel” by developing some new product development life cycle of their own. For once, the allocated time for their project would not be enough for such an effort, and for another, a newly-developed project life cycle without going through the test of time like others being available on the market may not be reliable to any extent. The evaluation of the logical structures of the projects will be carried out directly by the project mentors throughout the whole timespan of their projects. For this, we had spent great amounts of time and money to retrain our faculty staff members on the knowledge and experience of product development life cycles as well as useful related tools.

**Design Effectiveness**: Design is an important component in every electrical and/or electronic engineering project, and the mentors of each project will go along with their students through the design phase for every little assessment or evaluation needed. Typical questions about how much money the new design costs, how much energy the design helps save, how convenient it is to integrate the new design with other designs, etc. should be on checklist of every design evaluation forms. However, not every mentor masters the skills and knowledge in various aspects of controller design or circuit design or sensor design, etc.; as a result, we had made great efforts to closely connect our faculty staff members together for mutual consultation whenever needed. In effect, this requires not only additional overtime pay but also the frequent championship of departmental leadership in specific categories of electrical and electronic projects.

**Market ability** (of the products or services): To assess the market ability of some students’ products or product prototypes is a long shot even for our complete CDIO Project Evaluation Board. While the mentors can make any evaluation and grading on the projected marketability of their students’ products and product prototypes, only a few projects which are evaluated as exceptional on the above-mentioned evaluation criteria will be chosen for faculty-wide evaluation of their marketability. Every instructor and student will have the chance to do their rating on the market ability of these project as part of a transparent and democratic process.

Within the framework of the traditional CDIO model, item 2.1 will be evaluated during the Conceive phase, item 2.2 will be judged during the Design and Implement phases, and item 2.3 will be assessed during the Design phase; but within the scope of our new C-D-I-E model, all of the 2.1, 2.2, 2.3 and 2.4 items will be evaluated again in a much more comprehensive manner during the time period that was supposed to be for the Operate phase. Evaluations at this point tend to be more accurate now that we have had the students’ products or product prototypes from their Implement phase. Students from different project teams are also encouraged to add in their comments on other teams’ projects as well as on the evaluations of the involved mentors. In fact, this Evaluate phase has become very much a “bargaining” process amongst the students and their mentors about different aspects of their projects. This is very fruitful in helping students learn more from the feedbacks of different sources, and there is also plenty of time for students to gain new knowledge in the process, which is very much different from the short-time sessions of Q&A in any traditional board presentation.
C-D-I-E ASSESSMENT METHODOLOGY AND 3 CASE STUDIES DISCUSSION

In order to assess the effectiveness of our new C-D-I-E model, the Faculty of Electrical Engineering has run a series of similar CDIO Capstone Project classes in parallel, of which some classes adopted the traditional CDIO model and others adopted the C-D-I-E model. At the end of these project classes, students were asked to participate in focus group discussions to identify what and how much they had learned from their projects. The following three case studies will signify the different results from the two models:

**Case Study 1**

In this sophomore-level CDIO Capstone Project course, students were asked to create a household product which helps “dry coconut chips”. Students in traditional CDIO classes mostly started with their design work faster after doing research and review on products already available on the market. They mostly focused on either building the automatic relay to control the electrical current in the drying oven/machine to achieve effective drying results or redesigning the drying cabin space to maximize the oven efficiency. In contrast, because of the greater emphasis on the Novelty and Originality of their project ideas, students in C-D-I-E classes made up all kinds of new ideas: some used PID algorithm to control the exact temperature in the drying oven/machine at the user’s desire, others put in tubes to effectively evaporate and extract all the moisture in the coconut chips, and yet, others designed new oven cabin to prevent the coconut chips from getting burned, etc. In any case, product prototypes from traditional CDIO classes tended to resemble those already available on the market with some additional improvements. On the other hand, product prototypes from C-D-I-E classes had totally-new concepts or focused on new features. Some of these worked, and some others did not. In total, product prototypes from traditional CDIO classes turned out to have better Design Effectiveness and Market ability while those from C-D-I-E classes achieved more Novelty and Originality. Still, students from C-D-I-E classes admitted that they had learned much more, and had spent so much time on the projects as if this were some higher-level project.

**Case Study 2**

![Remote control project](image)
In this junior-level CDIO Capstone Project course, students were asked to improve on the functionality of a television remote control. Students in traditional CDIO classes again mostly looked up users’ comments about television remote controls on the Internet to determine what they needed to improve on: some changed the layout of the control buttons to make it more user-friendly, others change the circuit designs and sensors to achieve longer range in remote control, and the best was probably the one which removed most of the buttons and put in a touch screen for their television remote control. As for students in the C-D-I-E classes, some also came up with the same idea of using the touch screen for remote control, but there were also more interesting product prototypes like using gestures to control the TV through the Kinect (sensors) platform or integrating remote control features into smart phones simply by downloading some self-written apps. Eventually, some students even came up with the idea of integrating all the control of TVs, electric fans, A/C machines, etc. into one smart phone. Again, clearly enough, students in the C-D-I-E classes achieved greater Novelty and Originality for their project ideas, and while the Design Effectiveness and Market ability fluctuates from one project team to another no matter whether they were in the traditional CDIO classes or the new C-D-I-E ones, it seemed projects of those from the C-D-I-E classes yielded better future market prospects. It should be noted that since most projects from the traditional CDIO classes followed the traditional concept of a television remote control, they tended to have better logical structures and they followed along very well with their chosen product development cycle. In contrast, some projects in the C-D-I-E classes were not structured logically enough to meet their goals either because their scope were too broad and ambitious or because they were still ambiguous about their desired end outcomes for the project.

Case Study 3

In this senior-level CDIO Capstone Project course, students were sent to a rural area by the river and were asked to design some products of the top priority to the people living in that area. Given this open-ended project topic, students from the traditional CDIO classes eventually came to realize the importance of the Novelty and Originality in their project ideas. They were no different from students from the C-D-I-E classes about that point, and yet, there were certain differences: students from traditional CDIO classes tended to focus more on the technical capability of their teams for making a new product after their interviews with the locals living along the river about their utmost priority while students from the C-D-I-E classes spent time discussing and arguing about which problem on the list of the locals they should focus on and whether by solving that problem, they would be able to create some totally-new product - some product which would make a major difference. They worried less about the technical feasibility of their projected product because they believed one way or another they would get help in the process from their mentors or others throughout the duration of the project or during the Evaluate phase. As it turned out, students from both the traditional CDIO classes and the new C-D-I-E ones came up with all kinds of new and similar ideas of a flood-level warning system, a solar-powered water filtering system, an automatic watering system, an insect expelling machine, a solar-and-wind hybrid power supply system, etc., and while it was hard to judge projects through their names, when it came down to specific product features of similar projects, students from the C-D-I-E classes appeared to have more novel features even if some were not within their technical capability. In addition, students from the C-D-I-E classes tended to make the most use of their product development tools as their product design requirements were often more “open” and not as “predetermined” as those of students from the traditional CDIO classes, who in many unconscious ways usually predefined the limits of their product requirements through the
scope of their technical capability. As a result, students in C-D-I-E classes also tended to achieve better design effectiveness for their products.

As the case studies demonstrated, the C-D-I-E model helps promote students’ innovation capability by stressing the importance of the Novelty and Originality of students’ ideas while providing them with additional time and resource for better feedbacks and Evaluations. As a matter of fact, the adoption of the C-D-I-E model in CDIO Capstone Project courses by the Faculty of Electrical Engineering and Faculty of Information Technology at Duy Tan University has brought about a surge in the number of truly innovation projects during the last two years, as shown in Table 1 below.

Table 1. Number of Innovation Projects in the last 5 academic years

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<td>26</td>
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<tr>
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<td>1</td>
<td>14</td>
<td>11</td>
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<td>1.2</td>
<td>2.1</td>
<td>3.9</td>
<td>6.6</td>
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(Source: Department of Science & Technology Management, DTU)
CONCLUSION

Our study signified the fact that students in CDIO deployment usually do not receive a fair share of evaluation on their project work, which in turn will hinder the development of their innovation capability. The C-D-I-E model provides a good solution to this immediate problem, but an additional Evaluate phase alone would not be enough to enhance students' innovation capability and awareness. As a result, within our additional Evaluate phase, we have introduced a new and comprehensive set of major evaluation criteria for CDIO projects, namely the Novelty or Originality, Logical Structures, Design Effectiveness and Marketability of the project ideas, product, product prototypes, and other project related components. The emphasis on the degree of Novelty or Originality and Marketability of the C-D-I-E model clearly have enhanced students’ motivation in creating innovation features in their project; however, the amount of Design Effectiveness and Logical Structures in a project still fluctuates between the new C-D-I-E model and the traditional CDIO one, depending how much structured the project topic is, which is worth additional future study of this subject.

REFERENCES


**BIOGRAPHICAL INFORMATION**

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DEVELOPING COLLABORATIVE LEARNING AND
ENTREPRENEURIAL CLIMATE – TEN YEARS OF ICT SHOWROOM

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Jerker Björkqvist
Åbo Akademi University, Finland

Seppo Virtanen
University of Turku, Finland

ABSTRACT

More than ten years ago, the Information and Communication Technology (ICT) education units of Turku University of Applied Sciences, University of Turku and Åbo Akademi University aimed at facilitating their faculty to create and develop project-oriented learning activities. The result of this CDIO-inspired initiative was ICT ShowRoom, an annual exhibition and competition event open for all student projects of the campus. Since then, there has been a series of successful ICT ShowRooms; the 10th anniversary event takes place in March 2017. The amount of student teams participating the event has grown and the quality of the projects has been clearly improved since the first rounds. Yet much has changed during these years – both in the global and regional education arenas. Different forms of collaborative learning, university-industry activities and startup entrepreneurship facilitation are much more strongly present in higher education than when the first ICT ShowRoom posters were designed. In this paper, we reflect the motivators behind the ICT ShowRoom collaboration and the goals it has aimed at over the years. Also the challenges and possible future directions of the joint venture are discussed. Is the ICT Showroom needed anymore? How does this discussion relate to the CDIO initiative and its future steps?

KEYWORDS

Entrepreneurship, Capstone, ICT, Design-Build Projects, Student Competitions, Standards: 2, 5, 8, and 9

INTRODUCTION

Project-oriented courses are important tools for learning core engineering knowledge, skills and attitudes. Getting the opportunity to familiarize oneself in a hands-on fashion with the product and system lifecycle development and deployment is vital for students. This way they
develop product and system building skills and get to apply engineering science to practice (Crawley et al., 2007).

More than ten years ago, the ICT education units of Turku University of Applied Sciences, University of Turku and Åbo Akademi University seek joint ways to convince the faculty members and institutional administrators of the importance of creating learning activities of this type. The universities had decided to develop their cooperation by moving the activities of these three ICT units to a single building in 2006. This created a joint campus for students, faculty members and staff of all three departments. The joint campus and the different project-based courses offered by the units led to an initiative by the authors to find a way to promote student projects and, at the same time, to get both students and faculty members to become familiar with each other and the ongoing activities.

The decision was made to launch a joint competition between the student projects that focused not only on technical implementation details but also on the business ideas behind the projects, as well as on the presentation skills of the teams. The result of the brainstorming was the ICT ShowRoom – an exhibition and competition open for all student projects of the campus. The intention was to create an event with good spirit and a relaxed atmosphere – but still set up a real competition with an industrial jury and considerable prizes for the winner team. The marketing of the pilot implementation was started in late autumn 2007.

Since then, there has been a series of successful ICT ShowRooms; the 10th anniversary event took place in March 2017. The event has become an integral part of the academic year gathering students, staff and industrial representatives together. The amount of student teams participating in the event has grown and the quality of the projects has clearly improved since the first rounds. The early participants and competition winners have grown to experienced professionals many with entrepreneurial backgrounds. The early development steps and experiences of the ICT ShowRoom event and the different drivers behind it have been reported by Björkqvist, Roslöf and Virtanen (2009, 2012).

Yet much has changed during the years – both in the local, regional and global educational arenas. Different forms of collaborative learning, university-industry activities and startup entrepreneurship facilitation are much more strongly present in higher education than they were at the time when the first ICT ShowRoom took place. For example, the event was originally the only local venue for the students to present their projects to a larger audience including a clear twist of startup spirit. Today, there is a multitude of different student competitions, hackathons and innovation camps available.

In this paper, we reflect the original motivators behind the ICT ShowRoom collaboration and the development towards the goals it aimed at over the years. Also the challenges and possible future directions of the joint venture are discussed. Is the ICT Showroom needed anymore? How does this discussion relate to the CDIO initiative and its future steps?

BACKGROUND – ORIGINAL MOTIVATORS

Åbo Akademi University had for many years had a project course, with the objective of performing a "large scale software project in a group". The challenge was that the students were unmotivated, they did not really see why they should invest a lot of their time in a project that had low visibility and only one or two lecturers as reviewers. In year 2007, the
Faculty was invited to a presentation event of the projects – immediately the projects attained a completely new level of student commitment. One of the projects of that year is actually a company today.

At the same time, the Information Technology education of three higher education institutions in Turku, Finland, moved under the same roof. The organizations were Åbo Akademi University, University of Turku and Turku University of Applied Sciences. All these institutions had ICT-related project courses facing similar challenges. The basic problem with the courses was the lack of student motivation for doing project work on a regular basis and delivering a final deliverable at the assigned time. Another challenge was that the general curriculums did not include education on project skills. Furthermore, some of the faculty members did not consider these project-based activities very important opportunities for learning.

Inspired by the experiences from the previously mentioned course, and the fact that we had all IT students under the same roof, the idea of a common project exhibition event was formed. Already from the beginning some basic concept where formed, some of which have disappeared and some have remained during the years. The original framework of the concept is illustrated in Figure 1 (Björkqvist, Roslöf and Virtanen, 2009). The basic concept was to invite student projects to a competition and an exhibition. The event was named "ICT ShowRoom", and the first event was held 7 March 2008. In March 2017, the 10 year anniversary event was held.

![Diagram of ICT ShowRoom concept framework](image-url)

Figure 1. Original ICT ShowRoom concept framework (Björkqvist, Roslöf and Virtanen, 2009).
ICT SHOWROOM CONCEPT IN A NUTSHELL

In short, the ICT ShowRoom is a one day event during which the local higher education students present their projects made during the past year as a part of coursework. The organizers provide a poster stand and a table for demonstrations. The student projects participate in a competition as part of the event. Although the event itself is rather short, the preparation to the exhibition is a vital part of the concept. The project groups in the participating institutions are informed about the future event early, and they are step by step coached towards the ShowRoom event that forms an important milestone of the projects of the academic year. The registrations to the event are done using a web based system, where the participants in the first stage register the project name, members, abstract and contact information. Later on, the posters are submitted via the same system, and then collectively printed at a print house by the organizers. In addition, a program leaflet and other documentation (team and jury instructions) are prepared in advance.

The ICT ShowRoom day starts before 9 AM with setting up the stands and preparing the demos for the audience and the jury members. The exhibition itself runs four intensive hours from 10 AM until 2 PM during which the event is visited by hundreds of participants – including other students, faculty members and industrial representatives. After the winners have been announced and the exhibition dismantled usually about 3 PM, it is time to head to an "after ShowRoom" party organized by the local student entrepreneurs association.

A group of local industry professionals both act as members in the jury and sponsor the prizes given to the winning team. The jury assesses the technical contribution and quality, commercialization potential and presentation of the student projects. The jury spends two hours in the event familiarizing themselves with the student projects, and discussing the ideas and solutions used in the projects with each student team. The jury members give immediate feedback to the students about their views on the operability and implementation of the project. The event also includes a public voting in which visitors of the event may vote their favourite presentation and technical content. A certificate of appreciation is given to the winning team of each category. One of the voters is randomly picked to win a prize.

Figure 2. Visual image of the ICT ShowRoom 2017.
EXPERIENCES AND IMPROVEMENTS DURING THE YEARS

In general, already the first ICT ShowRoom event was considered successful and it was decided to be repeated the next academic year. In spring 2017, the 10th anniversary ICT ShowRoom took place.

*Industrial jury*

One of the main ideas in the ICT ShowRoom event is the jury consisting of company representatives. The motivation is that the evaluation of the student project should be based on external judgement. This has shown to be a very successful element in the concept. The fact that faculty members do not participate in the decision making facilitates the mentor-oriented role of the project course teachers; they are 'on the same side with the students'. Also the opportunity (and requirement) to present the projects to potential future employers tends to motivate most of the students to use their full potential.

Also the jury members need to truly focus on the projects in order to be able to present a solid judgement. The jury is free to select the criteria they use, they but should be able to present these criteria to the students in the prize ceremony. During the years, the size of the Jury has remained almost the same, 4-8 persons. The companies represented since the start of the ICT ShowRoom are listed in Table 1. One company has participated in every event: Vaadin (former IT Mill). Vaadin is a major employer of our students.

Table 1. Companies represented in the ICT ShowRoom jury throughout the years.

<table>
<thead>
<tr>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Oy IT Mill Ltd</td>
<td>• eCraft</td>
<td>• Oy IT Mill Ltd</td>
<td>• DNA Oy</td>
<td>• Logica</td>
</tr>
<tr>
<td>• Ixonos Oyj</td>
<td>• Oy IT Mill Ltd</td>
<td>• Sanako Oy</td>
<td>• Ixonos Oyj</td>
<td>• Moosedog</td>
</tr>
<tr>
<td>• Nokia Oyj</td>
<td>• Sanako Oy</td>
<td>• Sofokus Oy</td>
<td>• Logica</td>
<td>• Nokia</td>
</tr>
<tr>
<td>• Teleste Oyj</td>
<td>• Teleste Oyj</td>
<td>• Teleste Oyj</td>
<td>• Sanako Oy</td>
<td>• Teleste</td>
</tr>
<tr>
<td>• Turku Science Park</td>
<td>• Turku Science Park</td>
<td>• Turun seudun ohjelmisto-yrittäjät r.y</td>
<td>• Vaadin</td>
<td>• Vaadin</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Accenture</td>
<td>• bambuser</td>
<td>• Anders</td>
<td>• BoostTurku</td>
<td>• AgentIT</td>
</tr>
<tr>
<td>• BoostTurku</td>
<td>• BoostTurku</td>
<td>• Innovation</td>
<td>• Medbit</td>
<td>• Cadmatic</td>
</tr>
<tr>
<td>• ECraft</td>
<td>• Cerion</td>
<td>• BoostTurku</td>
<td>• Sofokus</td>
<td>• Progman</td>
</tr>
<tr>
<td>• Hibox</td>
<td>• Teleste</td>
<td>• Cerion</td>
<td>• Teleste</td>
<td>• Sofokus</td>
</tr>
<tr>
<td>• Vaadin</td>
<td>• Vaadin</td>
<td>• Crosskey</td>
<td>• Vaadin</td>
<td>• Staria</td>
</tr>
<tr>
<td>• Walkbase</td>
<td>• Nortal</td>
<td>• Teleste</td>
<td></td>
<td>• Vaadin</td>
</tr>
<tr>
<td>• Varsinais-Suomen IT-yrittäjät ry</td>
<td>• Turku Science Park</td>
<td>• Turku Science Park</td>
<td>• Vaadin</td>
<td>• Wapice</td>
</tr>
</tbody>
</table>
Prizes

The idea of the competition has remained to have only a sole winning team. The winner would get a prize that is significant enough, is somehow "state of the art", and possibly inspires further engineering experimentation. The prices are personal for each member of the team. The price has been aimed at 300 € per item, sponsored by the jury members and other industrial participants of the event. The prizes awarded are listed in Table 2. The prizes represents quite well the development of consumer electronics during the past 10 years.

Table 2. Prizes awarded to the winning team's members.

<table>
<thead>
<tr>
<th></th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nokia 810 Internet tablet</td>
<td>ASUS EEEPC Internet tablet</td>
<td>Buffalo Linkstation Duo</td>
<td>Galaxy S Smart Phone</td>
<td>Nokia Lumia 820 Phone</td>
</tr>
<tr>
<td>2013</td>
<td>Nexus 7 tablet</td>
<td>Bose QuietComfort headphones</td>
<td>Bower&amp;Wilkins T7 Speakers</td>
<td>Parrot AR.Drone 2.0</td>
<td>Suunto Traverse sports watch</td>
</tr>
</tbody>
</table>

Trends in the projects

During the years, we have collected titles, abstracts and posters of all the projects. Since 2015 we have also collected information on project type (technology used) and domain (business area targeted). From that information, we can directly derive some quantitative data, but also some qualitative data can be obtained. In Table 3, data for number of projects, number of people in the teams and number of companies represented are shown.

Table 3. Quantitative trends

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td># Projects</td>
<td>27</td>
<td>24</td>
<td>27</td>
<td>30</td>
<td>31</td>
<td>33</td>
<td>69</td>
<td>66</td>
<td>69</td>
<td>49</td>
</tr>
<tr>
<td># Research projects</td>
<td>15</td>
<td>14</td>
<td>10</td>
<td>12</td>
<td>8</td>
<td>10</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td># Student participants</td>
<td>174</td>
<td>135</td>
<td>163</td>
<td>167</td>
<td>134</td>
<td>189</td>
<td>374</td>
<td>358</td>
<td>268</td>
<td>317</td>
</tr>
<tr>
<td># Companies</td>
<td>5</td>
<td>8</td>
<td>13</td>
<td>13</td>
<td>11</td>
<td>10</td>
<td>9</td>
<td>9</td>
<td>8</td>
<td>9</td>
</tr>
</tbody>
</table>

During the ten years more than 2000 people have been involved in working on and presenting projects in ICT ShowRoom. This has, for sure, had some effect on the attitude to the ICT project work in the region. During the same time we have also seen a major change in the start-up culture in Turku, as in the rest of Finland. BoostTurku (http://boostturku.com/), a student startup society, gained momentum in 2011, with the event Summer of Startups. This was later rebranded to Startup Journey. The City of Turku, reorganized their startup-supporting activities into SparkUp (http://www.sparkup.fi/en), which today provides facilities for both staff supporting startups and the activities of BoostTurku. ICT ShowRoom has always been closely working together with BoostTurku and SparkUp.

From Table 3, we can see that the largest number of participating companies and organizations was during years 2010-2011. The number of companies sponsoring the events has been depending on the activity of the organizers, as participation in events like ICT ShowRoom is much driven by personal contacts. However, we also see a clear connection with the need for recruitment in companies and their involvement in ICT ShowRoom. Since
2015, the teams have classified their projects into technology and business domain. In Tables 4 and 5 the data is shown. Please note that the students can report the same project to several technologies/domains, hence sums of percentages are over 100.

Table 4. Reported technology used in projects (percentage of all projects that year).

<table>
<thead>
<tr>
<th>Technology</th>
<th>2015 (%)</th>
<th>2016 (%)</th>
<th>2017 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cloud</td>
<td>2</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Desktop</td>
<td>41</td>
<td>35</td>
<td>26</td>
</tr>
<tr>
<td>Embedded systems</td>
<td>6</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>Hardware</td>
<td>5</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>IoT</td>
<td>3</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Mobile</td>
<td>56</td>
<td>47</td>
<td>26</td>
</tr>
<tr>
<td>Web</td>
<td>35</td>
<td>37</td>
<td>20</td>
</tr>
</tbody>
</table>

Table 5. Reported domain of project (percentage of all projects that year).

<table>
<thead>
<tr>
<th>Domain</th>
<th>2015 (%)</th>
<th>2016 (%)</th>
<th>2017 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business administration</td>
<td>3</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Communication</td>
<td>3</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Education</td>
<td>15</td>
<td>31</td>
<td>17</td>
</tr>
<tr>
<td>Games &amp; entertainment</td>
<td>61</td>
<td>53</td>
<td>37</td>
</tr>
<tr>
<td>Healthcare</td>
<td>20</td>
<td>18</td>
<td>9</td>
</tr>
<tr>
<td>Infrastructure service</td>
<td>8</td>
<td>14</td>
<td>6</td>
</tr>
<tr>
<td>Public service</td>
<td>11</td>
<td>20</td>
<td>8</td>
</tr>
<tr>
<td>Sustainable development</td>
<td>5</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Other</td>
<td>12</td>
<td>16</td>
<td>8</td>
</tr>
</tbody>
</table>

We see that most projects are aimed for desktop, mobile and web, with similar figures for each year. During the years, there has been some technological changes in the environment. As iPhone was released in 2007, there has always been a number of apps targeting mobile phones. However, since Android has gained market shares, and today Android phones are very common among students, mobile apps today mainly target Android devices. Games & entertainment applications have been most popular in years 2015-2017, and this is similar to earlier years. However, it is worth mentioning that a game has not won ICT ShowRoom since the very first year. Even though it is not clear from the data, there has been an increase in the number of projects connected to topics in healthcare and education.

Table 6. Winners of ICT ShowRoom

<table>
<thead>
<tr>
<th>Year</th>
<th>Winner</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>Men vs. Women Quiz - A Facebook trivia application</td>
</tr>
<tr>
<td>2009</td>
<td>MOOR - system for handling orders in a restaurant</td>
</tr>
<tr>
<td>2010</td>
<td>Signbook - International sign language video dictionary</td>
</tr>
<tr>
<td>2011</td>
<td>Green Fus - follow-up system for alternative energy</td>
</tr>
<tr>
<td>2012</td>
<td>Chilly Framework - versatile game development framework</td>
</tr>
<tr>
<td>2013</td>
<td>Remote Alert Project - simple sense-and-report system</td>
</tr>
<tr>
<td>2014</td>
<td>WHISPR - anonymous location based messaging app</td>
</tr>
<tr>
<td>2015</td>
<td>Celia Dyslexia - application that helps you identify dyslexia</td>
</tr>
<tr>
<td>2016</td>
<td>Escflow - Food waste monitoring system</td>
</tr>
<tr>
<td>2017</td>
<td>Kill the DJ - voting system for background music in public places</td>
</tr>
</tbody>
</table>
In Table 6 the winners are listed. As organizers of the ICT Showroom event, having the opportunity to follow the work of the Jury, supported by the list of winners, we argue that what matters for attaining the interest of the jury is to do good solid work on a theme that inspires the students. Projects that have a logical role in the society and local environment also have an advantage. When it comes to quality of projects, we can generally see a solid improvement, and even more clearly, the quality of the presentation of the projects has improved significantly. The last two years, almost all projects have had good and clear presentation and demonstration at the ICT ShowRoom event.

**Improvements and challenges**

The original idea was that the research projects of the participating departments would be presented at the ICT ShowRoom exhibition as well (outside the student project competition). The motivation behind this was to improve the visibility of the state-of-the-art research topics among the students and, accordingly, make the research staff more aware of the students' achievements. However, this did not function very well. Despite extensive "internal marketing efforts" only a few research groups joined the event and, even if they did, they often just brought their posters on the wall and were not actively present at the event. Thus, the research project track was eventually removed from the event in 2015.

Every year, one of the goals has been to also attract local media to join the event and publish stories presenting the student projects. The results have varied significantly between the years. In some years there have been nice reports with photos in the main regional newspaper and news flashes in the local cable TV and radio stations meeting or even exceeding the visibility goals. Yet, some other times the event has received, in practice, no media coverage at all. The reason for this variation remains unclear; the process (press releases supported by the organizing institutions' media departments) has remained rather similar throughout the years. University internal media has noticed the event and the annual results nicely every year and the event seems to have found a well known place in the annual event calendar.

All the ten ICT ShowRoom events have been organized in the same premises. The ICT-City building that was originally built as the joint base of the higher ICT education of the city of Turku (previously called ICT House) has served as the venue from the very beginning. The practical arrangements have been smooth, usually just implementing small improvements each year based on the previous experiences. However, the ICT departments of the University of Turku and the Åbo Akademi University moved to another building recently and thus the original idea of a common arena for all the organizing departments is no longer present. The 10th anniversary event was still decided to take place in the traditional venue but this may change in the future.

As discussed above, the presence of the industrial participants is an important part of the event. The registration fees are used to cover the prizes and most of the direct organizing costs and, most significantly, the contribution of the industrial jury is a vital part of the concept. The amount of participating companies has varied from year to year (see Table 3) and sometimes it has required a lot of efforts to get enough companies to join. As one of the main motivators behind the companies' participation is recruitment needs, the economical situation of the region and its ICT-oriented businesses reflects the interests in the event.
THE FUTURE OF THE ICT SHOWROOM – WHAT NEXT?

Since the very first ICT ShowRoom event, the environment has changed significantly. One of the original drivers behind the event was to facilitate the opportunities and importance of project-based learning and, not to forget, to boost entrepreneurial attitude among the ICT students. Today, the different organizations, including all the higher education institutions, are more start-up friendly than ever. There are several support functions available for entrepreneurship-minded students and, one could say, it is much easier to be driven into the start-up world than it was for ten years ago.

Also the world of project-based learning has changed a lot. Opinions judging industrially-oriented project courses as a waste of time are very rarely present at the university halls anymore. On the other hand, the scene is full of all types of project competitions, seminars, hackathons, game jams and innovation races. One could argue that participating in these types of events have become mainstream – or maybe even "old school" already. Has the ICT ShowRoom event served its purpose already? Yet, the event has become an integral part of the academic year of the ICT departments and the strengths are still valid. Project deadlines are kept very well, the industrial jury plays its role nicely, and many of the students are prepared to take the next step towards entrepreneurship after gaining some practice on a safer ground first.

So, the story of ICT ShowRoom will most probably continue to its second decade. The concept should still be developed in order to meet the current environment better. For example, there could be more social elements utilized already during the project year facilitating collaborative spirit among the project teams. The use of different social media streams or, for example, short video presentations instead (or supporting) the traditional static posters could be interesting options to consider.
Another challenge is connected to the main title and theme of the event and competition in general. The mission of ICT ShowRoom is to focus on projects in the ICT domain. Yet, this domain is very wide and it tends to connect to other fields faster and deeper than ever. On the other hand, many current project course frameworks do not limit the topics to ICT only but cover multiple disciplines instead. Thus, keeping the event's focus on ICT prevents the participation of some teams in the competition. The project course leaders are forced to find something else for those teams – or they start inventing new competitions with a general multidisciplinary focus. Should ICT ShowRoom take this role of a general student project innovation event; or should it keep its original mission?

CONCLUSIONS

In this paper, ICT ShowRoom, an annual exhibition and competition event open for all ICT-connected student projects in Turku, Finland was presented. The event has been organized and developed for several years already; the 10th anniversary ICT ShowRoom took place in March 2017. The development and both the quantitative data and the qualitative analysis on the concept were presented and discussed. In short, the event has become an integral part of the academic year of the participating institutions, and it is well known on the local industrial arena and, especially, on the start-up entrepreneurs' scene.

Yet much has changed during these years both in the global and regional arenas. Different forms of collaborative learning, university-industry activities and startup entrepreneurship facilitation are much more strongly present in higher education than when the first ICT ShowRoom posters were designed more that ten years ago. Different innovation competitions and hackathons are frequently available for students interested in these activities. Even though ICT ShowRoom represents just another local implementation of active and integrated learning, one could argue that the discussion of the past and future development of the event has connections to the path of the CDIO Initiative as well. The once innovative and pioneering concept shall be ready to adapt to the changing environment – as one of the proofs that reaching the original goals are much closer today than they were at the beginning.

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BIOGRAPHICAL INFORMATION

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ENGAGING WITH INDUSTRY STAKEHOLDERS TO SUPPORT PROGRAM DEVELOPMENT

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ABSTRACT

Luleå University of Technology (LTU) has adopted CDIO as the framework for developing its engineering programs. At the Department of Civil, Environmental and Natural Resources Engineering, there are two programs focusing on tunnelling, mining and rock excavation. Despite very positive prospects for professionals in the field, the number of students has decreased for the last two years. Further, program content might not reflect recent developments or new requirements in the industry. Therefore, the programs and their courses are taken under renewed consideration. Given the nature of the challenges facing the programs, it is in this case particularly important to inform of the planned development through a dialogue with stakeholders. Stakeholder dialogue is also a key feature of a CDIO curriculum development (CDIO Standard 2). This paper reports on a process of engagement with industry representatives, initiated through a meeting to discuss the competence of newly graduated from LTU as well as the future needs in the industry. The input will make it more visible what programme and course development work needs to be done in the nearest future. A continued support and feedback from the industry is warranted during the programme development.

KEYWORDS
Stakeholder dialogue, program development, learning outcomes, Standards: 1, 2.

INTRODUCTION – STAKEHOLDER DIALOGUE IN PROGRAMME DEVELOPMENT

The CDIO approach for engineering education reform advocates the use of stakeholder input in the programme development process. CDIO curriculum development starts with the
recognition that students need a high level of preparation for professional engineering practice (Standard 1). Therefore, program level learning outcomes should express a deep working understanding of disciplinary fundamentals, as well as personal, interpersonal and professional engineering skills – and these program level objectives should be validated with the stakeholders of the program (Standard 2).

The term stakeholder originates from business science literature, where it refers widely to "any group or individual who can affect or is affected by the achievement of the firm's objectives" (Freeman 1984, cited in Jongbloed et al., 2008). The stakeholders of an engineering program include at least the students, society in general, teaching faculty, government and taxpayers, employers in industry and the public sector including universities themselves. It is however often a delicate challenge to get input from these groups.

Engaging stakeholders is never a straight process of “taking orders” from them. The relationship between stakeholders and universities can be characterised as loose coupling, implying that the university is responsive to its stakeholders while fully preserving its own identity and logical separateness (Weick, 1976). After collecting input on its stakeholders’ interests, the university has to evaluate and select its own direction among the various wishes from a chorus of voices, including students, employers, society, the university itself, and the research community. It is also a matter of balancing short-term and long-term interests. Finally, the aims that the university decides upon must be realistic to achieve within the available time and resources, such as faculty competence.

BACKGROUND TO THE CASE

Programs in tunnelling, mining and rock excavation

Luleå University of Technology (LTU) has adopted CDIO as the framework for developing its engineering programs. At the Department of Civil, Environmental and Natural Resources Engineering, there are two programmes with a focus on tunnelling, mining and rock excavation. One of the programmes is a five year national MSc in Civil Engineering, with specialisation in Soil and Rock Engineering. The other is a two year international MSc in Civil Engineering, with specialisation in Mining and Geotechnical Engineering. The majority of the courses are shared between these two specialisations, and therefore the students graduating from these programmes have similar knowledge and skills within the area of Mining and Geotechnical Engineering, i.e. constructing and excavation in rock and soil. The graduates often become consultants, building entrepreneurs, buyers of services, and mining engineers.

LTU as a technical university has a long tradition of applied research and is therefore a university with close collaboration with the industry. Hence, within the field of mining and tunnelling there are continues dialogs with the industry regarding research issues and future aspects. The faculty often assume what content should be included in programmes and courses based on issues within research. Despite continues discussions and close collaboration it is seldom that education, courses and programmes are deeply discussed at meetings with the industry. At present there are compelling reasons to take the programs and their courses under renewed consideration. Despite positive prospects for professionals in the field, the number of students in the programs and specializations has decreased for two consecutive years, as shown in Table 1.
Further, the program and course content has changed relatively little in the last 10-15 years and might not fully reflect recent developments in the industry. Given the nature of the issues facing the programs, it is in this case particularly important to inform the planned development through a deeper dialogue with stakeholders.

Table 1. Number of students registered in last years of their study 2012 – 2017.

<table>
<thead>
<tr>
<th>Program</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017*</th>
</tr>
</thead>
<tbody>
<tr>
<td>International MSc in mining</td>
<td>1</td>
<td>5</td>
<td>7</td>
<td>11</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>MSc with specialisation in Soil and Rock Engineering</td>
<td>17</td>
<td>24</td>
<td>22</td>
<td>27</td>
<td>18</td>
<td>8</td>
</tr>
</tbody>
</table>

* Number based on registrants in the year before the last.

**Evaluation of the programmes and courses**

The university has implemented a new pedagogic concept (Wikberg-Nilsson & Gedda, 2013) and uses by that a model where each programme every second year do a self-evaluation regarding ten different areas (which are similar to the CDIO standards). The self-evaluation performed for the national civil engineering programme as well as the CDIO-evaluation showed that Standard 9 and 10 was graded with low values (1-2). To successfully implement CDIO the university, the faculty responsible for the programme and its courses need full commitment (Chuchalin et al., 2015). It is therefore very important to involve the faculty in the programme, both in the on-going CDIO implementation and in the continuous work. This regards the whole programmes and not just certain specializations. At the moment there is a lack of active and shared communication between the faculty and the programmes.

Based on the evaluation we get input on course level from the students at the programmes. A standardised questionnaire form has been developed and is used in all courses at LTU. The questionnaire form consists of both multiple choice questions and free-text questions. The examiner and the programme responsible receive compiled data from the questionnaire for evaluation. The course evaluations are then discussed at programme council consisting of teachers, programme students and sometimes industry representatives. The programme council meets four times per academic year. The current students focus on content and execution of courses and what was good or bad from the student perspective, i.e. workload, quality of lecturing, meaningfulness and feasibility of assignments, course structure, timely availability of information etc. They are seldom able to evaluate the quality of the courses from the perspective of their future working life. Therefore, the evaluation process is more relevant for short-term improvements of individual courses and to some extent the overall programme. It is necessary to implement other forms of communication between stakeholders and the programmes.

This paper will report exclusively on activities to engage with one stakeholder group, the employers. It is just as important to understand the views of other stakeholders, not least the students, however this is outside the scope of this paper.

**METHODOLOGY FOR COLLECTING INDUSTRY STAKEHOLDER INPUT**

In order to get input from employers, a one-day meeting was arranged at LTU in October 2016 by the head of undergraduate education and the program director (authors one and two). 11 representatives attended (16 were invited) to comment on the competence of
graduates as well as the future needs in the industry. There were representatives from the mining companies Boliden and LKAB (among them authors four and five), the Swedish and Norwegian road and railroad administration, and consultants (Ramböll, WSP, Industrial Management Solutions and Nitro Consult). Of the 11 employer representatives, nine were also themselves LTU alumni of one of the programs under discussion. One alumna had graduated from LTU within the last 5 years, two alumni within the last 10 years and hence the others more than 10 years ago. Also present was a CDIO expert (author three).

Structure of stakeholder meeting

The meeting was separated in four phases, starting with (i) an introduction and presentation of the current setup of the program and its courses, then a (ii) group work, followed by (iii) joint reflection and (iv) an introduction to CDIO and final reflections.

In the group work the representatives were divided into three rooms for a focus activity for almost two hours. The participants were asked to spontaneously express the desired competence and skills of the graduates and to describe the circumstances within their part of the industry on which they based their views. The participants were given the following prompts:

- When it comes to new graduates
  - What usually works well…
  - What we wish for…
  - When there are problems it is often about this…

- Thinking 10-20 years forward
  - What will be more important to learn at university…
  - What will be less important…

The group facilitators (the three first authors) held a low profile in the discussion, mainly capturing the discussion in detailed notes. After each participant had presented their views, they kept discussing and comparing with each other, but they were specifically instructed that they did not need to reach any agreement, as the program was interested in the full diversity of the views.

After a lunch break, the facilitator of each group reported preliminary results from their notes, followed by a joint reflection in plenary, about one hour discussion to compare and analyse the input. Finally, a brief presentation was given on the CDIO approach to engineering education development. The final discussion came to focus on the appropriateness of CDIO to address the particular needs that had been delivered earlier, and on the conditions for change at the university. Also, the issue of industry collaboration to purposefully support the programme development was raised.

In the following, we present and discuss the results of the meeting, followed by reflections on the format for the meeting as a stakeholder dialogue activity.
RESULTS

Comments on new graduates

The stakeholder representatives had many positive things to say about LTU graduates. Typical comments were that they have the right curiosity and appetite for learning, and a self-driven and independent approach. The seven month internship at a company was seen as an important factor to strengthen this attitude, as it seems to help students see themselves in the role of engineers. The stakeholders confirmed that industry needs self-driven employees who can actively find their answers and solutions to problems, in a structured and cooperative way. Graduates were also commended for their good basic knowledge. Some suggested that their specific knowledge could always be deeper, or more relevant for a certain branch of the industry, but in the end there was strong agreement that such specific demands should never set the agenda for the education. The general viewpoint can be illustrated by this quote:

“We do not expect a graduate to be a ‘finished product’, but a person who we can continuously support in their development for our specific activity.”

The industry representatives also identified some main issues that need to be considered in the program and that they thought should be strengthened. The main suggestion for improvement can be summed up as “holistic approach”. While the graduates are often good at handling a specific technical issue, they had problems to see them in the light of the process as a whole. There is a risk of sub-optimization, when the engineer fails to understand their part of the work in an overall view. Further, most decisions are not solely based on technical considerations, but they may also be affected by legal aspects (e.g. contract relations), considerations for time, cost, safety, environmental impact, etc., or even just the need for predictability in relation to such issues. If the engineer has an overly narrow view on their role, it can also have consequences for the ability to communicate and cooperate with others who are involved in the process.

One remark shows how important it is to introduce the holistic view early in a programme, since students will benefit already from the beginning and throughout their whole education. With improved initial understanding they can take on the courses in a better way:

“The sooner a student can see the whole picture, the better their understanding, and the better their motivation in the remaining courses.”

A related issue is that graduates seem to have something of a hang-up for finding the exact one right answer, in a dualistic or black-and-white sense. It was suggested that the students’ long experience of having their work evaluated by teachers, for instance in exams, contributed to this “right answer” attitude. The industry representatives were in agreement that new graduates need to be more open for different ways to handle a problem. In most cases, engineering is a matter of weighing different alternatives and finding a reasonable level for the solution, rather than a perfect one. This is also related to students’ ability to handle uncertainty, and making assumptions and estimations:

“Rock mass investigations are important for all engineers in the field. It’s a general skill, no matter where you end up working. But they also have to know how to interpret the data, and understand the uncertainties and how the assumptions play in. It is an awesome judgment sport!”
The industry representatives agreed that the courses should help students make more out of the cases, and see them less as a quest for the right solution, and more as general examples, to understand principles. This can take a larger role in the programs. As an example, in the planning and design of different constructions in rock there will be distinct differences in requirements, depending on what type of construction is built. A drift in a mine may only need to last a few months, while a railroad tunnel must not leak water for 120 years – and the extreme case is a nuclear waste depository built to last 10-100,000 years. While such projects have still much in common, these different demands result in different requirements and students must be able to adapt their thinking. The problem is that when students have only encountered one of these types of cases, they are not prepared to think differently. To optimize the design of a construction students also need a wider understanding of its function, the working environment, safety, impact on surroundings etc. Therefore, students need to experience a variation of requirements on underground constructions, and they need support to reflect, in order to understand both similarities and differences.

Certain aspects of courses are very much appreciated by the industry representatives, as they help the students develop a wider thematic understanding. Many of the courses in the programs include assignments and pre-defined technical problems that are linked to reality, e.g. by using real data, and in some courses students spend some time at site solving problems for the industry. Still, the stakeholders identified the need in the programs to highlight even more ill-defined and complex problems, containing e.g. legal, economical, ethical, and environmental aspects.

The industry representatives also noted that students use numerical modelling to solve problems in many courses. For some students, the focus of the education seemed to have created unrealistic expectations on the workplace, as they had expected the work to be all about making numerical analyses, when in fact this was a relatively minor part of the work. Similar to the remarks above, the stakeholders commented that graduates could easily use modelling tools, but not always analyse the results and see if they were realistic or not. Hence it seems necessary with more training and guidance on how to use rough estimations and verification of results, and much more reflection on what they are doing and why:

“There are so many sophisticated tools and methodologies that people stop thinking!”

Regarding students’ skills the employers commented that engineers always work in projects, ranging from one person to hundreds involved. It is therefore important to develop students’ skills in planning their own time, and the ability to coordinate a project.

“In the workplace, when you work with technology, it is all about people! You need to learn how to work with others already in the education.”

The life-cycle costs need to be considered in order to get a sustainable economy in underground constructing. Being costs-conscious and able to relate project and results to economy was something that the stakeholders suggested should be better integrated in the program courses. Instead of just determining and suggesting the amount of rock reinforcement for a tunnel, to name an example, the students should be able to also assess the resulting safety in relation to its costs.
What to learn for future mining and tunnelling

The industry representatives saw in particular the supply of engineers as a great challenge ahead for the industry. There are many large-scale projects in the pipeline, including increasing maintenance needs, at the same time when many engineers are about to reach retirement age. This also highlights the need for transferring knowledge between experienced engineers and newly employed graduates. The most precious abilities that the old engineers have gained through long experience, were precisely the holistic view, discussed above. This is an area where the narrow conception of engineering really has an impact.

The developments within the industry seem to only emphasise even more the wishes expressed above for the education. Both within tunnelling and mining the environmental issues, such as vibrations, noises, ground subsidence or settlements, have become more important in the last years. The legal aspects are already, but will also become more, important in the nearest future, especially within mining. To become resource efficient, and contribute to sustainable underground constructing, one needs to understand the context of the problem and realize that it is not just about the technical issues.

Students need to be aware of both the issues and problems that exist today but also which are the future issues to consider. Regarding the future, in a 10-20 years horizon, the main differences compared to today are likely to be (i) increased automation, (ii) increased depth of constructions and (iii) more focus on sustainability. The vision from the industry is to place fewer workers in the production area (in e.g. Nikolakopoulos et al., 2015) and make measurements of the rock mass less subjective. This requires an automated environment where machines, instead of humans, perform the monitoring and production. When more automation is introduced, the generated data needs to be analysed by our future graduates. With deeper mining the complexity of many problems will increase, such as logistics, more seismic events, ventilation on demand, rock mass stability, increased production costs, etc. More standardized solutions and design is likely to increase in the future in order to develop sustainable rock excavation. As a result of this the type of rock reinforcement and installations are pre-defined. Hence graduates needs to for instance be able to optimize the amount of reinforcement.

Other issues raised regarding the future was that the maintenance of rock excavations is likely to increase, given all the tunnels, mines and waste depositories that have been excavated during the 1900s and 2000s. Hence our graduates must be able to give suggestions on rehabilitation of underground constructions. For future constructions and in order to minimize the need of maintenance our graduates should consider the life-cycle costs.

Discussion and suggestions for industry-university collaboration

It can be a difficult task for representatives to speak for a wider group than to describe their own needs. In addition, it is often necessary to also consider underrepresented or absent groups. For instance, while present students can be directly represented, it is harder to hear the voice of prospective ones. In many cases we would want to better understand the perspectives of groups that have presently not been sufficiently attracted to engineering education. A programme may want to ask not only “who are our students?” but also “who should be our students?” (Jongbloed et al., 2008). As another example, it is easier to get access to the perspectives of the presently dominant employers of the programme, than to understand the needs of new or future forms of work. This may have consequences for
innovation and entrepreneurship, as it may for instance require a slightly different set of competencies to work in smaller companies, or in start-ups, than in large established companies or authorities.

The industry representatives identified several ways in which the sector could support university education. Among the suggestions were:

- Providing external lecturers. Their role should, above all, be to provide real cases and give a realistic picture of the holistic view, discussed above. They can also help with a view on future developments in the industry. However, it is important that the course responsible is available for dialogue about the place of the guest lecture in the course and the program, and its role in preparing for professional practice, and also be present at the lecture!
- Course responsible were warmly welcomed to practice in industry, at least for a few days every year. They can be arranged as visits for shorter or longer time, or even through consultancies. The main purpose is to stay informed about the present state in the industry and how our field work in practice.
- Student internships are considered extremely valuable, and should be compulsory for all engineering students.
- Study trips and field work are also valuable, and should be increased if possible. There are so many sites with on-going and interesting projects, and students should visit both the office and the site. We should also discuss methods for making study visits more active, and to build in reflections to interpret these experiences, to maximise learning.

CONCLUSIONS AND NEXT STEPS

Collecting and analysing stakeholder input, and making informed decisions on the programme objectives is only the first step, as expressing program goals in a document is not enough to develop an education programme (CDIO Standard 2). The next step in the program development is to assign the program learning outcomes to the course level parallel with the implementation of constructive alignment during 2017-2018. Thus, the responsibility of each course is expressed as course learning outcomes, which will make the function of each course in the program explicit (CDIO Standard 3). To reach an integrated curriculum we need an active and shared communication between the faculty and the courses. The extent to which graduates will actually fulfil the stated program learning outcomes will then hinge on:

1. the connection between courses and programs – that the course level outcomes taken together measure up to the intended program outcomes, and
2. the fulfilment of each course to teach and assess students according to its intended learning outcomes – also known as constructive alignment (Biggs & Tang, 2011).

We should build upon our strengths in courses and programmes, and improve by making changes where we are lacking. Connected to that and based on the comments from the industry, we need to use more real cases in our programmes where one right answer is exception and where the students have the possibility to weight different alternatives based on for instance method, technology, life cycle costs and safety. This should be implemented as integrated learning experiences (Standard 7) in order to make the disciplinary knowledge come alive through application, also to authentic problems and situations. Students also need to be better prepared for analysing different kind of data in order to realize if they are realistic or not and which are the most important to consider. Since collecting, verifying and
analysing data is an important focus and part of the content in several courses, this could be discussed in a thematic workshop for the faculty.

The investigations of a rock mass, which was highlighted as generic skill by the industry, have been improved and changed regarding requirements and techniques during the last 10 year. This is also the case for all steps within the process of building underground. The teaching faulty might not be fully updated in the process and what engineers do in such investigations. One suggestion from the industry was to have teachers as trainees for a limited time period. This is a clear action regarding faculty competence (Standard 9).

A part of the senior faculty at the research subject mining and rock engineering is taking a pedagogic course at LTU, closely linked to CDIO. Some examiners in the programmes are therefore aware of constructive alignment and have implemented it in their courses. However it has been obvious that written exams are the most common assessment method within the programmes together with written group assignments. The aim is to reach a program where all courses have a purpose, are arranged in a purposeful sequence, support each other and integrates professional skills, personal skills and interpersonal skills (Standard 2 and 3). Based on the comments from the stakeholder meeting and on-going developments work the program goal and objectives will be revised.

Employers and alumni of the mining and tunnelling related programs at LTU show a great interest in the on-going work with programs and courses and are willing to continue in dialogs and meetings in the future. Further discussion with the mining company LKAB was held in November 2016 with special focus on the course “open pit and underground mining methods”. At that meeting, the representatives from LKAB suggested that the program responsible should arrange a whole day workshop during 2017 in order to discuss more in detail all courses related to mining. A continued support and feedback from the industry is warranted during the programme development. This could be done by yearly thematic workshops, arranged by LTU, and by board meetings (Standard 2). The result and comments from the stakeholder meeting needs to be further communicated and discussed with both students and faculty.

In October 2017 a faculty development course will be held by and arranged in Luleå. It will be arranged with university partners from Luleå, Madrid and Clausthal, Chalmers, Delft and Limerick. A faculty course where presentations about engaging stakeholders as well as course and programme development work within mining related programmes will take place. At the event industry partners and research institutes from Sweden and Ireland will attend. The event will contribute to Standard 9 and 10.

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FORMING AND INTEGRATING SKILL SET
IN COURSES AND PROGRAM

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ABSTRACT

In the process of building and developing training programs based on CDIO model, the managers are not only concerned about the building of the knowledge chain but also about the integration of skill set into the program. The skill set is one of the key factors determining the success of a training program, especially CDIO-based ones. The integration of skills in the courses helps students understand the knowledge easily, efficiently, and effectively. However, it is not trivial to integrate the skill sets so that the benefits are maximized. In this paper, we describe a training model which has been deploying in our faculty. First, we systemize the skills in CDIO specification and select the ones that are necessary and should be implemented priority. Then, we consider and distribute such skills into each course as well as recommend the expected mastering level. The distribution must be equally and suitable in order not to overproduce pressure and difficulty for lecturers and students. Finally, for verifying the effectiveness of our model, we collect and analyze the evidence of the process of teaching and learning, following the chain of courses in the program. The evaluation shows that the integration of skill set is essential.

KEYWORDS

Knowledge, Skill, Integration, Assessment, Standards: 3, 8, 10, 11, 12

INTRODUCTION

Universities expect students apply what they learned well in the real life after they graduated. Currently, the teaching and learning activities in almost universities focus on teaching students on knowledge. Lecturers are focusing much to the content of the course. It is thought that when they are equipped with strong background knowledge, they can apply it easily to real-world problems after graduating. Thus, the school focuses much to the knowledge rather than the skills. However, this worked in the early days in which tasks did not require much creativity and adaptation. In the era of information and technology, things get changed very quickly, almost every day. Employees need to update their knowledge and skills continuously. Products get more complicated and sophisticated. Thus, it requires new knowledge and technology with appropriate skills. Even to maintain or gain the market share, capitalization and profitability, manufacturers are demanding more creativity as well as rapid and continuous innovation. To have highly qualified graduates, knowledge is necessary but not sufficient.
In 21st century, industry requires the effort and intellect of not only an individual, but also a team, or even sometime the participation of end-users. Students must be supported in mastering both knowledge and skills. Therefore, in addition to knowledge, students need to be equipped with skills such as critical thinking, inquiry and analysis, creative thinking, quantitative literacy, integrated learning, lifelong learning, ethics and professional behaviors. “A set of achievements – skills, understandings and personal attributes – that make graduates more likely to gain employment and be successful in their chosen occupations, which benefits themselves, the workforce, the community and the economy.

We also argue that the integration of skills in teaching and learning program is very important. So, we have been trying to integrate some key skills into curriculum in our faculty, which is Information Technology Faculty, Ho Chi Minh University of Science – Viet Nam Natural University (HCMUS-VNU). However, the integration of skills into technical courses is challenging. The problems are what the process of teaching and learning skills is appropriate; and how they are evaluated. In addition, the program should avoid making students overloaded with the school work. Our observations show that there are very few models of integrating skills into curriculum proposed now. Besides, the assessment methods applying for the model are not enough. Therefore, this paper focuses on how to design the curriculum combines between content and skills and how to bring the specific skills to the courses in our faculty.

The rest of this paper is organized as follows. Section 1 identifies the key elements of skill which are necessary for the curriculum. Section 2 presents the important of integrating skills in education program. Section 3 presents ITU (Introduce/Teach/Utilize) assignment for each key element to ensure their compliance with course objectives or learning outcomes. The level of skills is clarified in section 4. In section 5, we describe to form skills sequence with bloom taxonomy verbs and the teaching/learning activities are developed to demo the integration skills into courses. Section 6 defines the sources of evidence which are collected for assessment. Section 7 shares the evaluation criteria which helps students to understand what to do and how much effort to achieve the course objectives. Finally, we describe the collusion and research in the future in section 7.

THE IMPORTANCE OF INTEGRATING SKILLS

Donna Price (Donna Price, 2015) looks at the essential ‘soft skills’ expected by employers, and suggests strategies for how these skills can be integrated in the classroom to prepare students for the 21st century workplace. Soft skills (also called people skills, transferable skills, and employability skills) are general skills necessary for success at all employment levels and in all sectors of the labor market. Two documents — SCANS and the Framework for 21st Century Learning — identify skills necessary to be successful in today’s workplace. There is renewed interest in integrating workplace readiness skills in education as a result of recent US legislation — the Workforce Innovation and Opportunity Act (WIOA) — as well as the College and Career Readiness Standards (CCRS) for Adult Education.

A 2013 report from the Seattle Jobs Initiative indicates that 75% of businesses surveyed reported that soft skills were as important or more important than technical skills in securing entry-level employment. The 2013 Job Outlook report says that employers want good communicators who can make decisions and solve problems while working effectively as part of a team. What are some of these soft skills employers refer to? Are they really ready to work? a consortium of four corporations asked over 400 employers across the US, “What
skills are necessary for success in the workplace of the 21st century?” The essential soft skills cited by these employers are ones that are echoed by employers across the US: professionalism/work ethic, oral and written communication, and critical thinking/problem solving. What can we design the curriculum to integrate some of these essential soft skills?

Basing on the “Curriculum and Instruction: A 21st Century Skills Implementation Guide” report of Partnership for 21st Century Skills (Partnership, 2015), student mastery of 21st-century skills should be recognized as one of the most critical outcomes of the teaching and learning process. Therefore, it is necessary to develop and implement curriculum and instructional strategies that—by design—enhance these skills. And to meet the needs of the 21st century learner, schools will need to adopt a 21st century skills curriculum and employ methods of instruction that integrate innovative, research proven teaching strategies, modern learning technologies, and real world resources and contexts.

Career development learning is concerned with helping students to acquire knowledge, concepts, skills and attitudes which will equip them to manage their careers, i.e. their lifelong progression in learning and work. It is important to note that the current focus on the delivery of employability skills has also appeared to stimulate general interest in curriculum design. Therefore, program leaders or educational developers who are responsible for program need to ensure that those programs make a clear contribution to student employability. It is probably going into more detail than senior policy-makers want. The main idea is that employers value achievements that we find it hard to assess in traditional ways. The argument is that we need a more differentiated, program-level approach to assessment. This involves disrupting the assumption that assessment has to be about measurement and numbering and substituting the view that assessment is about judgment, which can take many forms (Peter T Knight, 2004).

As a result, we recognize that it is very important to integrate skills into curriculum in our faculty. Specifically, we have applied CDIO and deployed the process of integration into the undergraduate Computer Science program since 2011. Each year over 400 students come to our program. They are divided into small classes of 50 to 80 students. There are about a lecturer and two teaching assistants for each class.

The process of integration can begin by making a survey to find out what skills are necessary for our students in Vietnam social context now. The result of the survey shows in . Basing on the survey result, we designed the curriculum which these skills are integrated in. Besides, these skills are also designed from low to high level in both each course and courses sequence in program. We also build assessment method to evaluate the effective of designed program. This work is presented in more detail in the follow sections in this paper.

THE TECHNICAL SKILL SET TO DEPLOY IN PROGRAM

When designing curriculum and integrating key elements into courses, it is important to specify the courses’ context. For instance, in which year of the program are the courses taught? What are the levels of the students? Based on this, the importance of each factor could be identified in order for the students to achieve them all. Please note that the integration could be specified through the spiral model. That is to say, moving from lower to higher level through years; the skills must be higher and assessed accordingly. As the integration, CDIO (Crawley et al, 2010) suggests the three levels of acquired knowledge: I(Introduced), T(Taught), U(Used). Level I is about the knowledge that should be introduced
to students without going deeply in explaining why and how. Usually at this level, lecturers do not need to evaluate students. Level T requires lecturers to teach in a way that focuses on helping students understand thoroughly the content so that they can use it later in practice. The third one, level U, assumes students already understand the knowledge; as a result, the lecturers expect students to be able to apply or to enhance the ability to apply in other areas. In the same course, different levels can be applied to each element. Besides, different skill levels are also increase in courses sequence. For example, marking I/T means that the lecturers will both introduce and teach that element to students. It might be the case that students are at initial stages of knowing and understanding new concepts. For example, in integrating key elements of “teamwork skills” into courses in computer science major. We mark ITU and levels that student should be archived for each element as shown in Figure 3.

LEVEL OF EXPECTED ACHIEVING SKILLS

In program’s syllabus, we identified skills which we want to prepare students for future careers. Being aware of these works is, however, not enough. We also need to define level of expected achieving skills. Each skill will be measured in the scale of 5 based on Bloom Taxonomy (Anderson et al, 2001). Program leader, faculty and stakeholders will be involved to determine the most appropriate level of achieving skill which meet the requirements of the jobs. Besides that, program leader also need to consider space or equipment necessary for deploying and developing the skills of full. Average scores after balancing the availability of facility will be used as final level of skill which students achieve upon graduation. Figure 1 illustrate level of some skills in IT program at our university.

Figure 1. Survey about achieving desired level of skills in IT Program at VNU-HCMUS

This scores can be evaluated and modified each year based on statistical data which we gather from course results. Moreover, we have plans to invest in facilities and equipment, and enhance faculty performance to improve the level of skills. Next sections, we present how the skills are expressed in the form of intended learning.

FORMING SKILLS SEQUENCE WITH BLOOM TAXONOMY VERBS

With expected achieving skills, we select some importance courses which almost students will recommend to choose. That courses are also integrated skills which we would like to assess. In addition, the courses need to be selected through the learning process of students.
from first year to last year. Next, we construct skill sequence from the courses. For instance, in our Information Technology (IT) program, we select at least one course per semester in courses which are integrated skills. Figure 2 show courses which have teamwork skill.

![Teamwork skill integrated into IT program](image)

**Figure 2.** Teamwork skill is integrated into IT program

Ideally, we will select all courses for collect data and assessing the skill. However, that is overloaded with the number of courses and students in our program. Therefore, the selection of important courses helps us assess the skills with the limited resources. Moreover, we use ITU to present expected achieving at the sequence. Bloom’s taxonomy used to provide the description of “what students should do if they are to achieve the intended outcome”, for example, know, comprehend, apply, analyze, synthesize, or evaluate. The *introduce* (I), *teach* (T), *use* (U) categories may be mapped by the Bloom’s taxonomy. When the learning is *introduced* may imply that students will know facts, concepts, principles or conventions. Thus, level I typically correspond to *observe* level in Bloom’s taxonomy. *Model*, the next level, requires students to understanding what was learned. It means lecturers must teach (T) them. Similarly, the rest such as *recognize*, *correct*, and *apply* implies level U in ITU-matrix. Table 1 shows the Bloom’s taxonomy which we reference in (Anderson et al, 2001) with modified. It requires more efforts from students for higher levels.

**Table 1. Some verbs in bloom taxonomy (Anderson et al, 2001)**

<table>
<thead>
<tr>
<th>Bloom Taxonomy</th>
<th>Level</th>
<th>Verbs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.Observed</td>
<td>identify, watch, observe, hear</td>
<td></td>
</tr>
<tr>
<td>2.Model</td>
<td>attempt, follow, imitate, try</td>
<td></td>
</tr>
<tr>
<td>3.Recognize</td>
<td>discriminate, perceive, select</td>
<td></td>
</tr>
<tr>
<td>4.Correct</td>
<td>adapt, adjust, develop, improve, modify, practice</td>
<td></td>
</tr>
<tr>
<td>5.Apply</td>
<td>build, construct, create, design</td>
<td></td>
</tr>
</tbody>
</table>
With the verbs, lectures can be identified learning outcomes about the skill in their courses more easily. It means that learning outcomes in courses plays a certain role in the process of achieving desired levels. Courses in first semesters often begin with introduction to skill. In this phase, the students acquire basic knowledge about skill such as listing key elements, determining the order of execution. The students are required to apply the skill, modify it, or construct new process into specific circumstances in later years. Some requirements can be repeated across several semesters. That is similar to the spiral model (Crawley et al, 2010) in which it does not require learners achieve everything in the first round.

We put the verbs, ITU all together in skill sequence with ITU.x convention, where x takes value from 1 to 5 level in bloom taxonomy. Figure 3 shows teamwork skill sequence in IT program with ITU and level.

![Skill Sequence Diagram](image)

Figure 3. Selected courses to assess teamwork skill sequence with achieving desired levels

There are some points we have to consider when choosing courses in skill sequence:

- The skill is integrated appropriate courses which supporting the learning process. It means that student will use the skill to get essential knowledge and gain their interest in learning.
- All most students (about 70% to 80%) will register the courses in the sequence. Some courses in our program are fundamental, so we can focus on them to assess skills. However, some other courses are not required. It makes this factor can be difficult to implement. One of the workaround we applied is to change courses in the sequence based on the registration statistics at the beginning of each semester but must ensure that alternative courses have to integrate this skill.
- Lecturers in the courses, especially adjacent courses, are required to discuss about teaching and learning activities to ensure students are not overloaded or perform at the same skill level.
- Resources such as equipment, teaching assistants, faculty, … need to prepare for teaching and collecting frequency data for the target behavior.

After completion of the skill sequence, we need to consider how to integrate the skill into each course. This is important phase in skills development. In next section, we will describe our approach in detail.
INTEGRATING THE SKILL INTO COURSES

When integrating skill into courses, it is important to specify the courses' context. For instance, in which year of the program are the courses taught? What are the levels of the students? Based on this, the importance of each factor could be identified in order for the students to achieve them all. Note that the integration could be specified through the spiral model (Bac Le et al., 2013). That is to say, moving from lower to higher level through years; the skills must be higher and assessed accordingly. As the integration, CDIO (Crawley et al, 2010) suggests the three levels of acquired knowledge: I (Introduced), T (Taught), U (Used). Level I is about the knowledge that should be introduced to students without going deeply in explaining why and how. Usually at this level, lecturers do not need to evaluate students. Level T requires lecturers to teach in a way that focuses on helping students understand thoroughly the content so that they can use it later in practice. The third one, level U, assumes students already understand the knowledge; as a result, the lecturers expect students to be able to apply or to enhance the ability to apply in other areas. In the same course, different levels can be applied to each element. For example, in integrating teamwork skill into "introduction to IT1", we mark IT2 (Figure 3) means that the lecturers will both introduce and teach that element to students. It might be the case that students are at initial stages of knowing and understanding new concepts. We express all in learning outcomes of the course syllabus (Table 2).

Table 2. Learning outcome associated with teamwork in Introduction to IT1 syllabus

<table>
<thead>
<tr>
<th>LO</th>
<th>Description</th>
<th>Mapping To CDIO Program Outcomes</th>
<th>ITU</th>
</tr>
</thead>
<tbody>
<tr>
<td>LO1</td>
<td>Identify roles in a team and observe how to construct a teamwork</td>
<td>3.1.1, 3.1.2</td>
<td>I</td>
</tr>
<tr>
<td>LO2</td>
<td>Follow the guides to build a team and work in discussing about IT history.</td>
<td>3.1.2, 3.1.3</td>
<td>T</td>
</tr>
</tbody>
</table>

In learning outcome description (Table 2), we use verbs corresponding to desired levels which the course is assigned in skill sequence. Because this is almost the first course in the curriculum, students will be learned the teamwork skill at simplest level. The lecturer propose the simple problem which need the group to discuss to solve it. The lecturer form group by randomly selecting members from the class. The next step, students in group are asked to identify roles, activities and rules in the group. Of course, they can wonder why they need to assign roles, which roles are needed, which activities should be done or why the teamwork need rules, so on. They can make mistakes, but it is not important. After some experiences, we explain to students what they need to understand and can do better. We can give some group building in real life and show them how teamwork works. As a result, we help students archive the course learning outcomes. That is the example where we develop teamwork skill at beginner's level in Introduction to IT1 course. The following courses will continue to teach at a higher level. This ensures that skills are fully implemented in each phase of process and that is also limit the extent to which the course undertaken.
THE PERFORMANCE ASSESSMENT

When the skill sequence and learning outcome in each course have been identified, we evaluate how far students achieve intended objectives. The first, lecturers gather information to assess students. The question is posed that what information should be gathered? What evidence can be collected to document achievements? Therefore, the list of evidence is mentioned for assessing student learning. There are many sources of evidence, such as short essays, assignments, reports, and so on (Biggs et al, 2011). That evidence is often associated with innovative teaching method. Lecturers can actively choose the appropriate method to teach and collect data for assessing. Besides that, the same activity or evidence can be used to show the achievement of different skills/behaviors. For example, thought questions can be used to illustrate the achievement of “identify” or “observe” in level 1 of teamwork and critical thinking skill. Table 3 presents some sources of evidence corresponding to levels in bloom.

Table 3. Behaviors and source of evidence

<table>
<thead>
<tr>
<th>Level</th>
<th>Behaviors (verbs)</th>
<th>Source of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Observe</td>
<td>Identify, Watch, Observe</td>
<td>Thought question, Peer Observation</td>
</tr>
<tr>
<td>2. Model</td>
<td>Attempt, Follow, Imitate</td>
<td>Role playing</td>
</tr>
<tr>
<td>3. Recognize</td>
<td>Discriminate, Perceive</td>
<td>Group Discussion</td>
</tr>
<tr>
<td>4. Correct</td>
<td>Adapt, Adjust, Develop</td>
<td>Oral Presentation</td>
</tr>
<tr>
<td>5. Apply</td>
<td>Build, Construct, Create</td>
<td>Project-based learning</td>
</tr>
</tbody>
</table>

The next step is to identify criteria for assessing gathered evidences. Based on the criteria, the performance level is defined, such as capstones, milestones, and benchmarks. Each one is scored as a number. The criteria and the rubrics should be defined clearly for the students to understand and to be able to do a self-assessment. Moreover, the grading process must be valid, reliable, and fair (McMillan, 2000). For example, criteria are developed for evaluating recognize level including: discriminating clearly and comprehensively, give necessary information to show a deep understanding. With high competence, students are required to ensure the sufficiency and even more than expectation. For example, if a student wants to achieve the capstone level, he/she must consider problem carefully, describe it clearly and comprehensively, and deliver all relevant information necessary to show a deep understanding. However, if the student considers the problem without clarification or description details, he only reaches the benchmark level. Table 4 is used to illustrate rubric of the teamwork skill.
Table 4. Rubric for teamwork skill (Peter J. Gray, 2012)

<table>
<thead>
<tr>
<th></th>
<th>Capstone 1</th>
<th>Milestones 2</th>
<th>Benchmark 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Working with Team</strong></td>
<td>Rarely listens to, shares, is not patient with, and is competitive with team members.</td>
<td>Usually listens to, shares, patient with, and supports the efforts of the team members.</td>
<td>Always listens to, shares with, is patient and encourages teammates.</td>
</tr>
</tbody>
</table>

In addition, the course must show the minimum passing level to ensure the desired quality. This is called the *passing standard* of achievement. For example, students with scores of 5 (out of 10) or more will pass. Otherwise, he/she fails.

In the last step of the performance assessment, we aggregate data streams from assessment data in each course of skill sequence. As a result, we will face with different types of data from courses such as different forms for the same skill levels, different number of students, various criteria, and so on. We set up an expert group to perform statistical and data extraction. Their mission is to create the statistical graph (Figure 4), show the data points abnormalities, interview students and lectures, get feedback from the parties on the skills of students (Figure 5). Based on that, program leaders will evaluate this overall results and identify which outcomes have the lowest student attainment. And then they offer solutions and change plans to improve the weakest part of the program in next phase.

![Overall Results about skills between 2015 - 2016](image)

*Figure 4. Overall Results about skills in 2015 and 2016*
CONCLUSION

The paper presents a process to integrate skills into courses based on CDIO approach. The process begins with identifying important skills which we intend to equip for students. Program leader, faculty and stakeholders discuss together to give achieving desired level for the skills based on facts. Next, we construct skill sequence with key courses which will be integrated the skill and chosen by almost student. The courses’ syllabus presents the skill in learning outcomes with ITU and Bloom’s Taxonomy. Then, teaching and learning activities are proposed to help students to achieve learning outcomes. In order to specify achievement levels, behaviors and sources of evidence are written down. In addition, criteria and standards are developed so that student can be able to understand clearly when he/she passes or fails; and what he/she should do to achieve desired objectives. Finally, we analyze data which collected from courses in skill sequence. As a result, we can identify areas for improvement in next phase of our education.

Figure 5. Skills survey from partner companies in 2016
REFERENCES


BIOGRAPHICAL INFORMATION

Bac Le, Prof. Bac Le is the Vice Dean of the Faculty of Information Technology. He is monitoring and controlling the progress of the project and the deliverables. He is an active member in adopting CDIO in FIT. Prof. Bac research interests are in Data mining, Soft computing and AI.

Thinh Le is a lecturer in the Department of Computer Science at University of Science (HCMUS). In addition to teaching, he also participated in the CDIO project at Faculty of Information Technology (HCMUS) from the beginning. Specifically, he was involved in the process of planning and structuring syllabus and material for some courses in the program following CDIO method. He and some colleagues researched about teaching methods especially active learning and has published papers in some international conference.

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TEACHING ENTREPRENEURSHIP: TO BE THE WIND UNDER STUDENTS’ WINGS

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The Hague University of Applied Sciences
Sustainable Talent Development Research Group

ABSTRACT

The CDIO network works with the extended CDIO syllabus version 2.0 (Crawley et. al., 2011), in which two learning goal sections were added: leadership and entrepreneurship. This paper focuses on entrepreneurship and uses a case study of the Eye on Entrepreneurs (EoE) initiative in the Netherlands to reflect on the similarities and differences between the CDIO learning goals in entrepreneurship and the unconventional approach of EoE in teaching (engineering) students entrepreneurship in practice. Eye on Entrepreneurs (EoE) offers a student an intense learning experience in an informal but authentic learning context. What are the perceived strengths of their approach when it comes to effectively teaching entrepreneurship? When translating this back to the formal learning context of a university, how does this relate to the CDIO framework and syllabus especially? And what would this mean for the lecturer’s competencies? Based on a case study discussion with practitioners an answer to these questions was sought. Both stakeholders from the (entrepreneurial) professional field (including talented students) and (entrepreneurship-) educators in general and from the CDIO-network were involved. The results show that what translates back to formal education is for teachers to be open minded, give space to manoeuvre and make mistakes, and have reciprocal dialogue and reflection with students when teaching entrepreneurship. Their main role should be to recognize talents and stimulate them to take initiative, show empathy and take risks in creativity.

KEYWORDS

Entrepreneurship, Authentic Learning Environment, Integrated Learning Experiences, Teacher Attitudes, Teaching Competencies, Standards: 2, 3, 7, 8, 9.

INTRODUCTION

Entrepreneurship in CDIO

Crawley et. al. (2011b) present the updated version of the Extended CDIO Syllabus v2.0. The syllabus is a blueprint for the learning goals of undergraduate engineering programs worldwide to educate engineers who can engineer. Together with the CDIO standards it forms the basis of the CDIO framework, which is used by over 120 universities worldwide. The syllabus was extended with leadership and entrepreneurship. Entrepreneurship involves
the redirection and mobilization of capital and human resources to form a new economic activity within an established firm, or to start a new company altogether (Crawley 2011a). It was established that engineering education should prepare students for both forms of entrepreneurship. One of the reasons to teach future engineers entrepreneurship is that innovative and viable business ideas are more likely to emerge in technical and creative programs compared to business schools (Kontio, 2010). Therefore, it was also recommended by the OECD (Organisation for Economic Co-operation and Development). For successful engineering entrepreneurship three ingredients were mentioned: engineering, engineering leadership, and specific domain knowledge associated with business formulation and start-ups.

Leadership was the other added learning goal in the CDIO Syllabus v2.0, which was also seen as intrapreneurship or leading innovation. There is an overlap between leadership and entrepreneurship, and between the two of them and the skills already in the CDIO Syllabus v1.0 such as Ethics, Equity and Other Responsibilities (2.5), Teamwork (3.1), Enterprise and Business Context (4.2) and System Thinking (2.3) (Crawley et. al, 2007). But in order to capture the additional skills needed to lead innovation and start a new business, section 4.7 and 4.8 were added to the Extended Syllabus v2.0, see Table 1.

Table 1. The added items to the CDIO Syllabus v2.0.

<table>
<thead>
<tr>
<th>4.7 Leading Engineering Endeavours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creating a Purposeful Vision</td>
</tr>
<tr>
<td>4.7.1 Identifying the Issue, Problem or Paradox</td>
</tr>
<tr>
<td>4.7.2 Thinking Creatively and Imagining Possibilities</td>
</tr>
<tr>
<td>4.7.3 Defining the Solution</td>
</tr>
<tr>
<td>4.7.4 Creating New Solution Concepts</td>
</tr>
<tr>
<td>Realizing the Vision</td>
</tr>
<tr>
<td>4.7.5 Building and Leading an Organization and an Extended Organization</td>
</tr>
<tr>
<td>4.7.6 Planning and Managing a Project to Completion</td>
</tr>
<tr>
<td>4.7.7 Exercising Project/Solution Judgment and Critical Reasoning</td>
</tr>
<tr>
<td>4.7.9 Invention – the development of new devices, materials or processes that enable new goods and services</td>
</tr>
<tr>
<td>4.7.10 Implementation and Operation – the creation and operation of the goods and services that will deliver value</td>
</tr>
<tr>
<td>4.8 Engineering Entrepreneurship</td>
</tr>
<tr>
<td>4.8.1 Company Founding, Formulation, Leadership and Organization</td>
</tr>
<tr>
<td>4.8.2 Business Plan Development</td>
</tr>
<tr>
<td>4.8.3 Company Capitalization and Finances</td>
</tr>
<tr>
<td>4.8.4 Innovative Product Marketing</td>
</tr>
<tr>
<td>4.8.5 Conceiving Products and Services Around New Technologies</td>
</tr>
<tr>
<td>4.8.6 The Innovation System, Networks, Infrastructure, and Services</td>
</tr>
<tr>
<td>4.8.7 Building the Team and Initiating Engineering Processes (conceiving, designing, implementing and operating)</td>
</tr>
<tr>
<td>4.8.8 Managing Intellectual Property</td>
</tr>
</tbody>
</table>

Mäkimurto-Koivumaa et. al. (2013) confirm that developing an entrepreneurial mind-set and behaviour is needed and valued in today's working life and that these abilities should be acknowledged when designing curricula for an engineering education (CDIO standards 7 and 8). They also indicate that teachers' pedagogic skills in higher education need attention. They recommend teachers to learn about entrepreneurial learning and action-based learning methods, and to utilize them as well. Their action plan also includes personal development plans for students and utilizing or developing networks.
Norrman et. al. (2014) recommend incorporating four elements crucial for learning in CDIO-based engineering education in entrepreneurship and leadership: a flipped classroom, experiential learning activities, sharp live cases and theory-based practical exercises. The flipped classroom can enhance self-paced learning that according to Hattie (2008) is one of the more important aspects of learning and can also enhance a reciprocal student-teacher interaction. Learning activities let students experience forms of problem-solving, role-playing, or other engaging kinds of “doing”. Real life cases where students work for or together with a real client make it clear that there is not one true answer only and increase student engagement. And theory-based practical experiences prevent problems students typically have, applying what they have only learned in theory during classes in a more complex context, by offering theory during dedicated workshops. This is in line with the just-in-time approach to offer knowledge in complex learning processes of Merriënboer & Kirschner’s 4C/ID method (2012).

Kozlinska (2016) challenges the belief that learning by experience is most effective in teaching entrepreneurship at business school universities in her doctoral thesis. Contrary to expectations, ‘learning-by-doing’ approaches did not necessarily lead to better outcomes for the over 500 students she studied, or even have adverse effects in some instances. Given the nature of entrepreneurship entailing uncertainty, ambiguity and dynamism, learning by doing seems intuitively right, but often students aren’t as experienced in this learning style as they are in more traditional educational settings and haven’t learned how to reflect on their doing for the learning to become effective. Secondly often educators either are entrepreneurs with little teaching experience, or teachers with limited or no entrepreneurial experience or experience in industry. And last courses in entrepreneurship often aren’t long enough to create a measurable impact. Looking in hindsight, successful graduates proved to have a high level of creativity and self-confidence, a strong passion for entrepreneurship and a tolerance to failure.

**Informal Entrepreneurship Education: Eye on Entrepreneurs**

Eye on Entrepreneurs (EoE, 2017) is an ongoing collaboration between entrepreneurs, investors, medium-sized companies, and regional universities and vocational schools around The Hague in the Netherlands. It started in 2014 with a coaching project for talented entrepreneur-students at university. The mission of the organization is to facilitate entrepreneurial talents’ development to become the best entrepreneurs of the Netherlands. In the vision of EoE this will further the prosperity of society. For this purpose, students are put in charge of a medium-sized enterprise with a ‘challenge’ for a year. There are mentors and coaches available to scaffold the steep learning curve of the talents on demand.

What are the perceived strengths of this approach when it comes to effectively teaching entrepreneurship? When translating this back to the formal learning context of a university what would this mean for the teacher’s competencies? And how does this relate to the CDIO framework? Based on studying the case of EoE and discussing it with practitioners these questions are answered in this paper. First the method steps are explained, next the results are summarized, and finally the conclusions are drawn based on these results.

**METHODS**

To become familiar with the Eye on Entrepreneurs (EoE) initiative and its way of working, over the course of a year four network meetings and talent selection sessions were observed.
and interviews were held with the two founders of EoE and one of the talents, an Industrial Engineering student of The Hague University of Applied Sciences, who later on became director of EoE. Based on this information the EoE approach has been described.

**EoE Network Workshop**

To establish the perceived strengths of EoE, question 1, two parallel workshop sessions were organized for stakeholders of EoE during a monthly gathering of the network. 21 people participated, a mix of entrepreneurs, advisors, board members, new talents, 'old' talents, and educators of universities and vocational schools. They were asked what they thought were 3 important (educational) strengths or factors of success for EoE why talents learned so much about entrepreneurship in a relatively small amount of time. Everybody wrote their answers down for him/herself before they discussed them in the group. The factors that were mentioned more often and were perceived as important by the participants were written down on a central flip-over. Then the question was asked if these factors could be translated to a formal educational setting and if so, which competencies would teachers in their eyes need to make this happen (question 2)?

**Interactive Case Study discussion**

The resulting perceived strengths and competencies of effectively teaching entrepreneurship by the EoE stakeholders were clustered and listed. They were used in an interactive case study presentation at an educational practitioners’ research conference: the European Association for Practitioner Research on Improving Learning (EAPRIL) conference in Porto, November 2016. During this session, the input of educators on the matter was compared to the input of the EoE stakeholders. Four European educators in higher education were present and one of the EoE talents. First the participants were asked to write down their opinion: What teaching competency is decisively important when teaching entrepreneurship to 17-25 year olds? The answers were compared with the outcome of the EoE workshop. And the talent who was present at the interactive presentation gave his view on the matter. Next the participants wrote down: What elements have you just heard that resonate with you? Why? This was discussed as well. Next the challenges of EoE when it comes to teaching were presented together with the strengths from the EoE workshop. The session was concluded with the question: To which of these strengths could you as an educator contribute in a formal educational setting? How? Again, the opinions of the talent were taken along in the discussion to get input from the students' perspective as well.

**CDIO Educators’ Online Questionnaire**

To answer the question how EoE’s findings relate to CDIO, question 3, a questionnaire was sent out to educators from universities of the CDIO network. There were 26 respondents from different European and South-American CDIO universities, of which two were applicant universities: The Netherlands, Sweden, Denmark, UK, Ireland, Finland, Portugal, Spain, Brazil, Chile, and Colombia. Respondents could choose factors of success combined with the CDIO syllabus items on entrepreneurship and the teaching skills that came out of the first two sessions. They were asked what teaching competency they deemed decisively important when teaching entrepreneurship to 17-26 year olds, and which factors (personal teacher traits, didactic principles and content building blocks) they would use in an entrepreneurship course. In these lists the CDIO learning goals of Table 1 were added. Would they choose these learning goals or other things to make the course effective?
RESULTS

The EoE approach

Observation and interviews gave insight into the way EoE works. EoE’s talent scouts operate in business and schools to recruit young entrepreneurial talent. When interested, these potentials have to pitch themselves and their plan for one specific company-case at an EoE board meeting. They also have to do a Big Five test, the personality test that looks at extraversion, agreeableness, conscientiousness, neuroticism and openness, for more background information (Hensel, 2010). If selected, the talents get the opportunity to be the CEO of the existing medium-sized company they pitched for, for a full year. The company typically has up to 50 employees, and a minimal turnover of 200,000 euro per year. Talents get a coach to support their personal development and help them reflect. They also get a mentor who is specialized in the sector to share his/her own entrepreneurial expertise, e.g. business models, finance or marketing. The business networks of all these EoE’s accelerators are at the disposal of the student. It is a demand-driven, one-one-one guided educational model.

Eye on Entrepreneurs goes beyond teaching the theoretical basis of entrepreneurship, by teaching practical skills in a truly authentic, yet guided learning environment. EoE believes in learning by doing and making mistakes. The learning is reciprocal, like Norrman et. al. (2014) discuss, and the student is treated as a professional from day one. There is pressure on the learning process, as the students solve problems for an existing company with real employees, revenues etc. But the learning is also self-paced and just-in-time by learning on demand, instead of by being offered a pallet of workshops, classes or introductions on certain topics. Besides discovering and applying domain specific knowledge, talents get opportunities to practice personal and interpersonal skills in investor meetings, dealing with personnel, and (re)starting company processes. Students are activated; already during the admission process they do their research in advance, pitch convincingly, and support their plans with solid arguments. This way, a talent can gain ten years of entrepreneurial experience in one year in both mind-set and behaviour.

One of the talents stated in an interview “I don’t need a teacher to give me a lecture, I can learn more by googling what I need to know at a certain moment to solve a problem or face a challenge”. Like Mäkimurto-Koivumaa et. al. (2013) EoE feels too much emphasis is placed on innovation and ideas in education, while the focus on personal development is often underappreciated. EoE leans on the ideas of Sarasvathy (2008) of effectuation. An entrepreneur takes decisions in a complex and uncertain context based on available means and resources, utilizing networks and leaning on an awareness of personal skills and competences. For this the entrepreneurial mind-set that is needed is one of being dynamic, flexible and self-regulating.

So far four talents have been placed in a company to become skilled entrepreneurs. One of the students has successfully run an indoor climbing hall for a year and then became director of the EoE organization.

EoE Network Workshop

The EoE network gathers frequently in the indoor climbing hall café, which has become their base. During these network meetings entrepreneurs, university lecturers, talents, mentors and coaches and other interested stakeholders gather. If there is a talent presentation, the
EoE council is the jury and others present are asked for their advice. During one of these meetings a workshop was organised to reflect on the strengths and success of EoE. The main question was: what are EoE’s strengths, and what can formal education learn from this?

What the EoE stakeholders indicated during the workshop were the strengths of the EoE initiative to teach talented students entrepreneurship so effectively within one year time is shown in Table 2.

Table 2. Stakeholder Perception of the EoE Strengths.

<table>
<thead>
<tr>
<th>Focus</th>
<th>Content</th>
<th>Didactics</th>
<th>Attitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Practice-based*</td>
<td>• The company is the starting point</td>
<td>• Challenging, exciting cases*</td>
<td>Personal traits of the talent:</td>
</tr>
<tr>
<td>• Wide network</td>
<td>• Talent needs to recognize the problem</td>
<td>• Real, authentic setting, with real responsibility*</td>
<td>• Personal ambitions, passion, and drive</td>
</tr>
<tr>
<td>• Talent recognition &amp; selection on passion and involvement</td>
<td>• Know the company and make it better: Sometimes it needs to be deconstructed and rebuild</td>
<td>• Experience with practice*</td>
<td>• Awareness</td>
</tr>
<tr>
<td>• Connecting*</td>
<td>• Know what kind of plans to have and when to sell</td>
<td>• Coaching on case &amp; on demand by expert entrepreneurs</td>
<td>• Dedication</td>
</tr>
<tr>
<td></td>
<td>• Personal development</td>
<td>• Flexible, tailor-made</td>
<td>• Trust</td>
</tr>
<tr>
<td></td>
<td>• Gather people around you who can add to your talents</td>
<td>• Freedom</td>
<td>• Pride</td>
</tr>
</tbody>
</table>

The focus and attitude factors show how personal development are central to EoE. Also, the content factors are more behaviour-oriented than theoretic-knowledge-based. During the workshop session, one of the coaches explained:

“…We have met a lot of people who were great at finances, but were terrible entrepreneurs. And vice versa. Therefore, the Big 5-tests we let students do are so interesting: what kind of a person is this? What are his talents? What is he incapable of? He could choose to devote a lot of attention to improving on what he cannot, but that’s a shame really. Because if he starts to excel in what he can do very well, he can become a fine entrepreneur.”

While interviewing one of the founders of EoE, the difference in didactics with formal educational settings and teaching became clear right away:

“…You have to keep an eye on them, but also give space. All sorts of crazy things can happen. You need to have faith; they won't fall in the ditch right away. They have common sense, just like you. They must push the limits, let it happen. It is sometimes so exciting, and sometimes quite uncomfortable. But you have to give them space. You have to dare to do that. It will trigger people with ambitions. Yes, even an 18-year old (former athlete) can lead a gym and learn in one year what normally would take about 5 years. He does have to prove that he knows the challenges of the company and learn to sell his plans at a shareholders’ meeting. He has to try out creative, eccentric stuff to get people's attention. Cramming essential entrepreneurial experience in one year; We are the wind beneath his wings. He must fall, absolutely, but must also land gently because he has to get up again and continue. That's what we provide for. “
Next the question was posed what formal higher education could learn from EoE. Focus was put on the role of the lecturer who teaches entrepreneurship. In Table 3 important teacher characteristics are listed for effective entrepreneurship education in a formal educational setting, according to the participants of the workshop.

**Table 3. Perceived Teaching Competencies for Entrepreneurship Education**

<table>
<thead>
<tr>
<th>Personal traits</th>
<th>Didactic:</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Show initiative*</td>
<td>• Give room to manoeuvre*</td>
<td>• Knowing what entrepreneurship is</td>
</tr>
<tr>
<td>• Entrepreneurial (or intrapreneurial)</td>
<td>• Coach students*</td>
<td>• Have an eye for entrepreneurial behaviour</td>
</tr>
<tr>
<td>• Guts</td>
<td>• Be flexible towards students</td>
<td>• Able to recognize talent</td>
</tr>
<tr>
<td>• Empathy*</td>
<td>• Feedback (give and receive) *</td>
<td>• Able to acknowledge talent</td>
</tr>
<tr>
<td>• Enthusiasm*</td>
<td>• Reward students</td>
<td>• Experience in entrepreneurship/practice</td>
</tr>
<tr>
<td>• Stamina</td>
<td>• Know the rules, don’t use them</td>
<td>• Link with professional world</td>
</tr>
<tr>
<td>• Open mind*</td>
<td>• Out-of-the-box in teaching</td>
<td></td>
</tr>
<tr>
<td>• Open to the world*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Inquisitive</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The participants talked a lot about the ability to recognize talent, and then facilitate those students with openness and flexibility via a reciprocal dialogue, based on equality. A link with the professional world was emphasized important as well.

**Interactive Case Study discussion**

The lists of Tables 2 and 3 represented the perception of the stakeholders around EoE. With the input of Table 3, the competencies that lecturers need to have according to the EoE stakeholders, a follow-up was done during the EAPRIL conference with a panel of educators in order to find a balanced answer to question number 2, what EoE meant to. Before the participant panel of educators at the interactive case study presentation at EAPRIL got to see these lists, they were asked what teaching competency (attitude, knowledge, skill...) they thought was decisively important when teaching entrepreneurship to 17-25 year olds. Despite the small size of the panel, and unaware that they did so, they picked several factors from Table 3, see Table 4. They also added two new factors: to have a work attitude, and personal self-efficacy related to entrepreneurship. The first was about giving the right example. The latter dealt with the self-perception of the lecturer’s abilities on entrepreneurship.

**Table 4. Perceptions of the EAPRIL educators on teaching entrepreneurship**

<table>
<thead>
<tr>
<th>Perceptions EAPRIL educators panel</th>
<th>Overlap with EoE list:</th>
<th>New aspects:</th>
</tr>
</thead>
<tbody>
<tr>
<td>What competency is most important for an educator when teaching entrepreneurship</td>
<td>• To be open minded and curious*</td>
<td>• Have a work attitude</td>
</tr>
<tr>
<td></td>
<td>• To be ready to take risks*</td>
<td>• Personal self-efficacy related to entrepreneurship</td>
</tr>
<tr>
<td></td>
<td>• To think outside the (school)box*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Have knowledge about entrepreneurship</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Have economic skills</td>
<td></td>
</tr>
<tr>
<td>Added after the discussion:</td>
<td>• Recognize talent</td>
<td>• Reciprocal dialogue with talents</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Offer opportunities for failure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Coaching on attitude</td>
</tr>
</tbody>
</table>
In the discussion that followed the comparison to the EoE list, the talent of EoE emphasized the importance of ‘acknowledging talent’ and ‘be flexible’ for him as a student. When asked after the discussion, the participants indicated they were most struck by his remark that teachers are experts in learning and thus they should focus on what they are good at and organize the rest. For instance, they could use real entrepreneurs as coaches. Also, the autonomy of the talent was mentioned by the panel. He chose his own mentor and the moments he wanted to be taught or try out things on his own.

Finally, when asked how they saw themselves contribute to entrepreneurship education as educators in a formal setting, they agreed they needed to listen more to students: when they succeed but also when they fail. They should offer them opportunities/possibilities instead of assessments, give the student room and help him to realize the right attitude. Also, they could facilitate building up a basic network. But before all of that they agreed it was important to recognize talent and have a reciprocal dialogue with them.

**CDIO Educators’ Online Questionnaire**

With the insights of the EoE workshop and in-depth discussion with the participants at EAPRIL, a first insight was obtained of what formal education could learn of the strengths of the EoE approach, specifically looking at what is offered in what way to the student by the lecturer. The last question addresses the relationship with CDIO. In Table 2 ingredients for CDIO standards such as integrated learning experiences (3), experiential learning in the ‘operate’ phase (7), and just-in-time activating learning (8) are covered in:

- Challenging, exciting cases
- Real, authentic setting, real responsibility
- Experience with practice
- DO, not just theory

These aspects have an asterisk in Table 2.

Even the aspects Kozlinska (2016) mentions that often miss to experiential learning successful are covered in the EoE approach: talents prove to have enough time to learn entrepreneurship by being a CEO for one full year full time, and mentors are entrepreneurs themselves, or hybrid academics with first-hand entrepreneurial experience.

Besides looking at the overlap between the perceived strengths of EoE and the CDIO framework and its engineering education research outcomes, there is also an overlap between the contents of entrepreneurship education mentioned by EoE and the EAPRIL educators on the one hand, and the CDIO syllabus list in Table 1 on the other, see Table 5.

### Table 5. What to teach (engineering) students in entrepreneurship education

<table>
<thead>
<tr>
<th>CDIO Syllabus items/learning goals for Engineering Entrepreneurship</th>
<th>Content mentioned by EoE during network workshop</th>
<th>Content mentioned by Educators at EAPRIL conference</th>
<th>Chosen by CDIO educators in questionnaire</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.8.1 Company Founding, Formulation, Leadership and Organization</td>
<td>Not mentioned</td>
<td>Not mentioned</td>
<td>Not mentioned</td>
</tr>
<tr>
<td>4.8.2 Business Plan Development</td>
<td>Not mentioned</td>
<td>Have knowledge about entrepreneurship</td>
<td>Mentioned by 19% of participants</td>
</tr>
<tr>
<td>4.8.3 Company Capitalization and Finances</td>
<td>Knowing what entrepreneurship is</td>
<td>Economic skills</td>
<td>Mentioned by 4%</td>
</tr>
<tr>
<td>4.8.4 Innovative Product Marketing</td>
<td>Not mentioned</td>
<td>Not mentioned</td>
<td>Mentioned by 15%</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>---------------</td>
<td>---------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>4.8.5 Conceiving Products and Services Around New Technologies</td>
<td>Not mentioned</td>
<td>Not mentioned</td>
<td>Mentioned by 8%</td>
</tr>
<tr>
<td><strong>CDIO Syllabus items/learning goals for Engineering Entrepreneurship</strong></td>
<td>Content mentioned by EoE during network workshop</td>
<td>Content mentioned by Educators at EAPRIL conference</td>
<td>Chosen by CDIO educators in questionnaire</td>
</tr>
<tr>
<td>4.8.6 The Innovation System, Networks, Infrastructure, and Services</td>
<td>Link with professional world</td>
<td>Not mentioned</td>
<td>Not mentioned</td>
</tr>
<tr>
<td>4.8.7 Building the Team and Initiating Engineering Processes (conceiving, designing, implementing and operating)</td>
<td>Experience in entrepreneurship/practice Have an eye for entrepreneurial behaviour</td>
<td>Not mentioned</td>
<td>Not mentioned</td>
</tr>
<tr>
<td>4.8.8 Managing Intellectual Property</td>
<td>Not mentioned</td>
<td>Not mentioned</td>
<td>Mentioned by 15%</td>
</tr>
</tbody>
</table>

A short digital questionnaire was sent out to CDIO members. The questions asked resembled those used in the EAPRIL discussion. The EoE strengths, which had some learning goals in it besides attitudinal and didactic elements, were supplemented with the CDIO learning goals for entrepreneurship in the questionnaire. Respondents received no prior information on the EoE initiative and why the EoE strengths were in the list. Without influencing their choices by any background information, they were asked to choose the 5 most important building blocks they would put in a course of project aimed at teaching entrepreneurship, and which they would absolutely not put in. Most votes went to:

- offering an authentic learning environment with real responsibilities (74%)
- getting a student out of his/her comfort zone (48%)
- let the student formulate the entrepreneurial challenge him/herself (44%)
- taking students seriously and consider them to be professional colleagues (41%)
- creativity (33%)

The CDIO learning goals weren’t in the top ten of building blocks, and business plan development got the most votes (5 out of 27 respondents). Remarkably, all syllabus elements that were mentioned (see Table 5) also were mentioned by 1-3 participants each under ‘what would you absolutely NOT put in your course’. In total 33% of the participants mentioned one or more CDIO syllabus learning goals in answer of this question.

When asked what were important competences for lecturers in entrepreneurship enthusiasm again was thought important, just like being open to the world outside the university. Being entrepreneurial, showing initiative and having empathy were following in the list. They wanted to give students room to manoeuvre in the course, coach them by giving and receiving feedback and think out of the box in their educational design(s). Also, an eye for entrepreneurship and active links with the professional world were deemed important. Their answers did lean towards the teacher knowing what entrepreneurship is, instead of (merely) facilitating the (reciprocal) learning process. All these aspects have an asterisk in the Tables 2, 3 and 4.
CONCLUSION

Although it is mainly anecdotal and has its limitations, this study gives some clear hints into the current perceptions of what role a teacher could play in effective entrepreneurship education. The answer to the questions were not meant as a search for something new, a success formula or fix for all. It was more concerned with listening to what is the common perception amongst education innovators, and not overlooking the insights already out there, be it in education or in practice.

What is so interesting about studying an entrepreneurship case like EoE is that it becomes more and more clear that to breed successful entrepreneurs, strengths often heard were giving students space and time and mutual dialogue. This was said even in a non-formal educational setting with lots of pressure on the (real) solutions, as real people and resources are involved. EoE says they pack ten years of experience in one, yet giving space, time, room to manoeuvre and room to fail are central themes. As one of the network workshop participants mentioned: “...Many entrepreneurs are lifelong learners by trial and error (especially the latter). They didn’t get the how to write your business plan classes, or practiced on theoretic cases. They learned by doing.” This notion seems to have been picked up by CDIO educators too, who in the questionnaire did not choose en masse for the well-known CDIO syllabus items for successful entrepreneurship education, but for the more attitudinal coaching on open mind, empathy and enthusiasm.

The question is if the aspects that did matter to the participants and respondents are captured in the CDIO framework as it is right now. Looking at the nature of the aspects mentioned, this should come back in standard 9: enhancement of faculty competence, and standard 7: integrated learning experiences. This research is a small beginning of giving direction to the personal and interpersonal skills of a teacher, integrated in the context of entrepreneurship.

The interactive case study discussion session was quite small-scaled, but none the less gave rich insights into the deliberations of the educators to see value in, or counter, the strengths of EoE in a formal learning setting. The educators who had experience in teaching entrepreneurship were quite on the same road as the EoE stakeholders. Best of all, the reciprocal dialogue which was mentioned as one of the important factors in the results took place during the discussion when the talent and educators together came to new insights in an open conversation on what value each could add to the learning process.

REFERENCES


**BIOGRAPHICAL INFORMATION**

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CDIO & COMPETENCE BASED CURRICULUM DESIGN TECHNIQUES: UNITEC COMPUTER SCIENCE PROGRAM REFORM

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Jorge García

Icoms Technologies, USA

ABSTRACT

Curriculum design is a challenging task, institutions need to close the gap from the demands of industry, the future demands of the global market, the expectations of the students, and the paradigms of the faculty. The final goal should be to secure, as much as it is possible, appropriate jobs for the students at the moment of graduation. To this end, this paper presents the experience that the faculty of the Computer Science (CS) Department in the Universidad Tecnológica Centroamericana (UNITEC) had in the latest CS Program reform, where CDIO was incorporated along with a competence-based curriculum design.

KEYWORDS

CDIO, Competence Based Curriculum, Computer Science, Competence Matrix, Standards 1, 2, 3, 4, 8

INTRODUCTION

UNITEC is a private university in Honduras that currently offers 10 engineering programs (Computer Science, Industrial, Mechatronics, Civil, Biomedical, among others). The university as a whole has a total enrollment of over 26,000 students, from which more than 5,000 are engineering students (Registrar Office, 2017).

Before 2008 UNITEC curricular model was a goal–content based curriculum, in 2008 the University decided that the whole model needed to be updated, and it changed its educational philosophy to a competence-based curriculum design. Since that point in time, all programs creation and reforms are built under this paradigm. Around 2009 some faculty in UNITEC (mostly from the Computer Science Department) participated in LASPAU sponsored workshops to improve engineering education that included the CDIO initiative, and at that moment engineering program design and teaching changed. In 2010 three engineering programs received accreditation from ACCAI (ACCAI, 2017), a regional accreditation institution, among these programs was the Computer Science undergraduate program. The
The original plan was to incorporate the CDIO initiative in the 2011 curricular reform, but accreditation had priority at that moment. After the accreditation process, the Computer Science program started its curricular revision, that was due in 2011, and the plan was to reflect the CDIO initiative there, and afterwards to run for an ABET accreditation. Several events prevented this plan to be fulfilled, and the program revision was done until 2014, at this time some CDIO standards were included, and the Engineering School has plans to start the self-study for ABET accreditation in 2017.

In Honduras the higher education authority is known as Higher Education Direction (DES abbreviated in Spanish), and it is the office of the government that regulates all higher education institutions (HEI). When a university wants to offer a new degree, there are certain requirements that must be met to be presented and approved by the DES before that program can lawfully operate in the country. Additionally when a program reaches 5 years after its creation or last update/reform, the program can be updated to conform to new market and industry demands. By law, all programs must be reformed before 10 years have passed since their last update or creation.

The previous CS program revision was in 2006, so as stated before the process was resumed in 2014, to be able to comply with the DES imperative program reform that was at that moment overdue. This program reform was a clear opportunity to incorporate the CDIO standards in the curriculum.

The success of the CS program rests in the soul of its design. Since the CS program was conceived in the late 1980’s, it had a strong emphasis in learning by doing, and in project based learning. Some other important characteristics are that students need to learn to learn by themselves, since technology changes so fast and there is no way that any university can provide the 100% of the corpus of knowledge in CS or Information Technology; the program has an inherent global market focus, training and education is always done considering that the students should be able to work anywhere in the world with their degree. Since its conception the program has had a capstone project (senior project) where every students must show that they have acquired the necessary skills to enter the job market. Currently, students can choose from capstone project or internship, depending on their preference. Another important trait of the program is that UNITEC has always tried to train entrepreneurs, so there is a entrepreneurship component in all undergraduate programs in the university. This shows that, even when it was not explicit, the CS program is inherently competence driven.

UNITEC’s mission statement is: “To develop leaders renowned for their global vision and social responsibility through an educational model based on competences, values, entrepreneurship, academic and technological innovation, internationality, research and social outreach”.

The recently revised mission statement of the university considers explicitly that all programs must be competence based, and should also include several features that align to the global economy that every day becomes more a reality. This mission guarantees that the leadership of the institution will support changes in the curricula and in the teaching philosophy to comply with a student centered – competence based education, a step forward to the complete inclusion of the CDIO initiative in the rest of engineering programs.

This paper will present the experience in the 2014-16 CS program reform where CDIO standards and competence based curriculum design played a significant role in the process...
of this curricular revision. The paper will present a brief background on the CDIO initiative, curriculum design and the challenges faced by engineering programs in Honduras. After the background is presented, there will be a description of the steps followed to achieve the 2016 CS program, then the achieved results of this reform to this date. Finally conclusions and future work is discussed.

BACKGROUND

CDIO Initiative

Technology is advancing at an accelerated pace, permeating all aspects of modern life. Engineering is the area of knowledge that provides the professionals that build and maintain this technology. Thus engineering is passing through a period of unprecedented change (Parashar & Parashar, 2012). To cope with this reality, the Massachusetts Institute of Technology in collaboration with Chalmers University of Technology, Linköping University and the Royal Institute of Technology founded de CDIO Initiative.

Engineering education traditionally was theoretical, and teaching was teacher centered (Kuang & Han, 2012), the result was producing graduates from the university that lacked practical experience and required further training to be able to produce in their jobs. Lecturers focused on the delivery of contents to fulfill their courses objectives without consideration of providing professional skills to the students. The effect was that engineering program was unable to provide the expected outcome from society.

CDIO Initiative comes to find convergence between theoretical knowledge and professional skills, both important in the job market. The heart of the initiative rest in its first standard that states that an engineering program needs to adopt the principle that “product, process and system lifecycle development and deployment use the model of Conceive, Design, Implement and Operate” (Bao, Gu, Lu, Xiong, & Chen, 2013; CDIO, 2017). The correct implementation of this model assures that engineering students will acquire the knowledge and skills needed for the job market.

Sometimes CDIO meaning is oversimplified to think that it is just project-based learning, when it actually means much more. For instance it considers the changes in curricula and courses design, the effects and impact in teaching, learning and assessment, and also the fact that the implementation should be continuously evaluated for improvement and sustainability (Bao, Gu, Lu, Xiong, & Chen, 2013). In addition to the impact in curricula, structure and teaching styles, CDIO goes even deeper, it proposes a new perspective in the student – industry approach (Bai, et al., 2013).

CDIO efforts are by no means isolated to other quality education improvements endeavor HEI pursue, by following the initiative, curricula places emphasis in graduates capabilities instead of qualifications thus becoming competence based. In addition to this advantage, by working towards the CDIO standards, the programs also get closer to accreditation standards (Bao, Gu, Lu, Xiong, & Chen, 2013; Soare, 2015).
Curriculum Design and Competence Based Curriculum

Designing a curriculum for any higher education program is a complex task that involves several parties and information. It is a delicate endeavor since it will have impact in the lives of the students that enroll in the program, and will affect also the industry where the graduates are going to serve once they finish the program.

The curriculum brings together several stakeholders: industry, students and alumni, state or accreditation agencies, politics and universities. Industry demands skilled workers that bring value to their companies, students want to land in “good” jobs when they graduate, politicians want to decrease unemployment and help create wealth, universities want to optimize the use of resources, lastly professors want to provide lifelong and meaningful education to their students (Schlingensiepen, 2014). Some additional issues that should be factored in are globalization, technology advances, social inequality and environmental changes (Parashar & Parashar, 2012). To successfully assemble all these factors is to come close to a successful higher education program that will satisfy all stakeholders.

Traditionally education has been teacher – centered and content – oriented, however recent advancements in teaching and learning have shown that it is better to change the focus of education from the teacher to the student (Parashar & Parashar, 2012). This means that bringing together all the stakeholders demands is not enough to have a favorable program, especially for the students. This is where competence based design comes in. Competence is defined as: “complex kind of learning outcome that is often related to skills, abilities, personality traits, capacities, knowledge, attitudes, values, etc.” (Soare, 2015). Competence based education closes the breach between the needs of the market and the outcome of education systems. The focus of this paradigm is on producing a professional that knows “how to do”, instead of only “knowing the theory”. Students have the pressure to find a job at the moment of graduation (Zhang, Wang, Li, & Shi, 2016), by switching to a competence based education, there is a higher chance that the future professionals will find job in the industry.

The goal of competence based education is to provide a hands – on experience to the student transferring focus from the books to projects (Bai, et al., 2013), to make the training relevant to the student, this way the information and skills will be “locked” in the brain of the student.

Engineering Challenges

Since technology is changing so fast, especially in information technology, it is difficult to update the course contents and academic programs to cope with these changes (Kuang & Han, 2012; Zhang, Wang, Li, & Shi, 2016). Some higher education regulations allow for some flexibility in their programs, thus letting them update up to certain point their contents and even overall program structure. In the case of Honduran regulations, programs do not have this flexibility. This reality forces curriculum designers to become creative in the definition of courses, in such way that some flexibility is gained, and updates can be done by professors without failing to conform to the official structure of the program. A consequence is that professors need to periodically update their courses to renovate according to the most recent advancements of their specialty.

Professors need to be motivated to engage with the new philosophy of continuous update, and competence based education; this challenge can be confronted with periodic workshops
by professors in engineering that share hands-on experience about these issues. This brings up another bigger problem, that is, to be able to have this frequent professional development with professors, and in UNITEC case is difficult since more than 90% of the professors are part time.

Zhang, Wang, Li, & Shi (2016) state that it is the responsibility of the HEI to train and educate students with the demands of the employers, this poses another issue, particularly in CS programs; it is very difficult to teach all of the employers demand with the four year time constraint of undergraduate programs. Some employers want students to graduate with specific tools training, and other employers with other different tools. A way to handle this problem is to have elective courses, and to provide extracurricular workshops on topics and tools that are popular at a given time.

METHODOLOGY AND RESULTS

Overview of Computer Science Program Curricular Reform

As it was mentioned, the key is to bring all information from the stakeholders together, and then formulating a meaningful program that will help create value to all. Figure 1 depicts the process that took part for the reform of de CS program. There are four sets of stakeholders shown in four layers: foreseeable future, global market, local market and students, faculty and alumni. These layers represent the different levels of information used to collect all relevant information for the reform. Starting from the latter one: faculty, students and alumni were interviewed and surveyed to gather data about the advantages and shortcomings of the previous CS program, three goals were sought: what needed to be kept or improved, what needed to disappear for lack of relevance, and what new things needed to be added to the program. At this level the most common suggestion was to add web and mobile development courses, and to add agile development methodology.

The next layer includes the national market and industry expectations. A meeting was held with industry representatives from companies that recruited a significative number of CS graduates. At this meeting it was discussed a proposal of the new program, and representatives had the opportunity to suggest changes that would help graduates provide value to their companies in shorter time. As it was expected, industry requested that specific products were taught: Visual Basic, Oracle, etc. Another topic of discussion was about the professional skills that they expect from CS professionals. Industry manifested that graduates needed to improve: communication skills, both oral and written, and teamwork. On the other hand industry requested more system administration and datacenter management courses and training. It is important to remember that companies are always looking for graduates that require the minimum amount of additional training, knowing this fact helps to trim their requirements and to synthesize them into competences that would serve most of them when they hire a graduate from the CS program. In contrast, most companies stated that UNITEC graduates needed the least time of additional training before becoming productive in their positions.

The next level of stakeholders represent the global market. Considering the constraint that it was not possible to visit international companies, a study was made using the ACM curricula report (ACM & IEEE CS, 2013) to seek clues on the demand of the global market of CS graduates. In addition to this report, some alumni working abroad were interviewed to gather information about the demands of international companies. It was found that, in general,
some courses of the UNITEC CS program had questionable relevance like compilers, algorithm analysis, theory of computation and the sort. However at this reform the designers decided to keep these courses as they provide competitive advantage to the graduated professionals. The international input supported the requests from local market to improve the web and mobile development subjects in the program. Skills were also confirmed, and there was an addition: language skills, working in the global market requires that professionals are proficient in English.

The World Business Forum published a report where the top 10 skills for the future jobs are: Complex problem solving, critical thinking, creativity, people management, coordinating with others, emotional intelligence, judgement and decision making, service orientation, negotiation and cognitive flexibility (Leopold, Ratcheva, & Zahidi, 2016). Even though the reform was done before this report was published most of these skills where identified supporting the information given by the stakeholders.

![Diagram of Curricular Revision Process](image)

**Figure 1. Overview of Curricular Revision Process**

The last layer: foreseeable future, represents an attempt to predict the changes in the following five to ten years, this is to keep the program in the vanguard in the universities market and to have courses that will be relevant before the next reform. It is arguable that this layer is based on guessing, but it is informed guessing using all available information about the tendencies of technology.

Once all the above mentioned data is collected, it must be analyzed and synthesized to produce the set of topics (knowledge) and the set of competences (skills) all graduates must have by the time they complete the program. Then, the flowchart of the courses is outlined and the set of competences is mapped into a competence matrix. This is revised later by focus groups that provide feedback for minor adjustments. By the time the flowchart and competence matrix is improved, the faculty is asked to write the synthetic program of each of the courses. The synthetic program is an official document that formally describes each of the courses in the academic program. At this moment the reform can go for official review at the higher education authority the DES.
Identification of Professional Competences

To determine the professional competences, a document was written with an initial list of competences that a CS graduate should have. This document was shared among several people around the world (US, Taiwan, Honduras, etc.) to contribute to the list, and to describe any suggestions if it was considered appropriate. After several months of revision the identified professional competences are as follows:

- Programming
- Systems Integration (3rd Party Libraries usage)
- API Development
- Unit tests and integration
- Operating Systems and Platforms
- Information Systems Development
- Web Application Development
- Mobile Application Development
- Math and Statistics
- Project Management
- Database design and management
- Computer Networks and Communication
- User Interface Design
- Software Engineering
- Information and Computer Security
Table 1: Excerpt of Competencies Matrix

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Legend:
- Reading Level 1: Basic
- Reading Level 2: Medium
- Reading Level 3: High
- Writing Level 1: Basic
- Writing Level 2: Medium
- Writing Level 3: High
- Synthesis Level 1: Basic
- Synthesis Level 2: Medium
- Synthesis Level 3: High
Identification of Generic Competences

As discussed previously, the CS program needed to be explicitly competence based, so there was an imperative on the identification of generic competences, also known as soft skills. The process was similar than the identification of professional competences, but there was an inclusion of input from professionals of other areas of knowledge, to have a more round up idea of what generic skills should the graduates have. The generic competences identified are:

- English
- Oral Communication
- Written Communication
- Business Communication
- Leadership
- Entrepreneurship
- Creativity
- Teamwork
- Professional Practices

The Competence Matrix

The heart of this curricular reform is the competence matrix, other authors have developed similar approaches to the mapping of competences. For instance (Schlingensiepen, 2014) proposed a Boolean matrix using competences as modules and showed where each competence should be activated. The experience of this curricular reform is that a Boolean matrix can be improved by using different levels of cognition or intensity.

Table 1 shows an excerpt of the matrix used to map the competences to each of the courses determined by each of the knowledge blocks. The matrix has four parts: the courses, the CDIO implementation, the professional competences, the generic competences. Notice that for each course a level of implementation of CDIO is indicated, where L1 means that only basics are introduced and L3 means that the course should give the full intensity of that skill. For instance the Data Structures courses have a low level of conception and high level of design, implementation and operation. The next part of the table shows professional competences, for each of the identified competence a cognitive level is defined. The cognitive level is chosen from the six cognitive levels expressed in the Blooms Taxonomy. As an example, in the Introduction to CS course, the course should train in Programming, Database and Software Engineering at the most basic level: Knowledge. The final part of the matrix shows generic skills, also mapped for each of the courses. The different levels mean the different level of demand on each of the courses, for instance in this excerpt English level of competence should be Basic Reading, as it is expected that students are able to gather information from English written references.

After carefully working with the competences matrix, it was time to write the formal description of each of the courses. To do so, all faculty received training in competence based education, and on the whole methodology used to design the CS program. This way each of the faculty would be able to write the synthetic program of the courses related to their area of expertise.

Synthetic Program Definition

Competence based curriculum design has three components: description of the competence (skill), means to assess it, and a standard to cast judgment of compliance with the acquired competence (Soare, 2015; Jones, Voorhees, & Paulson, 2002). It follows that this components need to be taken into account when writing the synthetic program. UNITEC’s format to write the synthetic program of each course includes information as competences,
conceptual and procedural concepts, attitudes, values and regulations, assessment methodology and indicators of accomplishment, among other general information.

Using the competence matrix each professor is able to determine the actual competences that need to be developed in the course. Then by using the Bloom Taxonomy verbs related to the cognitive level defined for each competence, it was easy to select the appropriate verbs to describe the competences and sub-competences that each course required, and the appropriate delivery method of each competence.

The other issue to discuss is that based on the new competence based education, the assessment methodology needed to be updated to reflect that the actual competences are being assessed and not the traditional list of contents the course requires.

To successfully write all the courses synthetic programs, a small team of faculty helped all of the rest on a one-on-one basis. This way all the documents were aligned to same tone using the experts in every subject.

CONCLUSIONS

The use of a scientific method for curricular reform has shown how to integrate the demands of all stakeholders in the design or reform of an academic program. At this moment the CS program has been granted approval by the higher education authority and is currently operating since the second semester of 2016.

Thanks to the usage of the competence matrix, it was easy to map all the competences required by stakeholders into each and all of the courses, and then it became a simple task to map this into the required by law synthetic program for each course.

CDIO initiative is completely aligned with competence based education, the current paradigm chosen by UNITEC, and it helped the CS program reform to come closer to the next accreditation process with ABET.

FUTURE WORK AND CHALLENGES

This work has brought more challenges to the CS department in UNITEC. Starting 2017 the chairman will need to start to train all faculty on the changes of paradigm. So far the program has been implicitly competence-based, but now it needs to explicitly take into consideration the changes in the way things are done. Starting 2017 the CS department is going to record the experience of taking this program design into the classrooms. It is believed that the major impact will be in the way that projects and practices are assessed, using indicators that help measure the acquisition of the demanded competences.

After the faculty is trained, there is a plan of creating a community of practice so that faculty – that in majority is part time – have the opportunity to share their problems and lessons learned.
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**BIOGRAPHICAL INFORMATION**

**Carlos Roberto Arias**, Ph. D. is the Research Director of the Universidad Tecnologica Centroamericana in Honduras. He held the position of Computer Science Department Chairman, and Computer Science Department Research Professor. During his time as full time faculty he actively participated in the 2006 and 2016 curricular reform of the Computer Science undergraduate program. His current research interest are eLearning and eGovernment.

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SIMPLE MOCKUPS - TOOL TO ENHANCE VISUALISATION AND CREATIVITY IN ENTREPRENEURSHIP COURSES

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ABSTRACT
The CDIO framework encourages us to work with prototyping during the conceive and design phases integrated into engineering education. At Linköping university, we apply prototyping and working with simple mockups in several entrepreneurship and innovation courses in order to stimulate creative thinking and experimentation. We have seen that through working with a joint prototype, the students increase their level of engagement and self-confidence while learning to know each other, both as individuals, and according to their skills and competence. Prototyping events are appreciated as learning activities, not least as they signal a culture of playfulness and unpretentiousness within a course. We have also seen that it is important to inspire the participating students to reflect on the event in order to complete the learning process. In the paper we analyse and discuss our experience regarding how and at what time in a course simple prototypes can be used, how workshops can be developed, and what we have learned.

KEYWORDS
Entrepreneurship, project course, prototype, mockup, shitty prototyping, CDIO standards: 2 (learning outcomes), 7 (Integrated learning experiences) and 8 (active learning)

INTRODUCTION AND FRAME OF REFERENCE
It has been stated that a picture tells more than 1000 words and whether this always is true can of course be discussed, but in most cases illustrations of various type enhance understanding, and this holds especially true for abstract or advanced items. This is probably why mankind has used sketches and models of different kind to explain things to each other for a very long time, from rock-carvings (see Figure 1) and models in case of stones, sticks and cones to advanced drawings and 3D printed items. Recent research has also shown that visualization enhances creativity and learning (see e.g. Berglund & Leifer, 2013). Therefore, it is a worthwhile endeavour to integrate visualization into our learning activities and courses.
Figure 1. The picture illustrate a wild boar hunting scene and the rock carving is to be found at Himmelstalund in Norrköping. Photo: (Theres Furuskog, Norrköpings stadsmuseum)

Prototyping is an advanced form of visualization and it is highly relevant for engineering education that often involves product and concept development. The CDIO framework encourages us to integrate prototyping into engineering education, in particular during the conceive and design phases, see for example CDIO syllabus 2.0 subsection 4.4.1 where “Experimental prototypes and test articles in design development” are specified and “Modeling, simulation and test” in subsection 4.4.4 (cdio.org). Furthermore, recent technological developments such as CAD and additive printing/3D-printing have made prototyping feasible even with limited resources that often set the boundaries for what we can implement in our courses and their contributions to learning experiences have been highlighted in previous research (e.g. Chin Tiong et al 2016). However, even without access to such advanced tools, prototyping can be integrated into engineering education in structured but simple ways and in a variety of courses - as we will demonstrate in the cases below. The paper aims to share our experience regarding fast and easy prototyping, for example through creation of simple mockups.

Fast prototypes are already in use in various contexts, both in the industry and in the context of education. Berglund and Leifer (2013) lists several purposes where prototypes can be beneficial and among these the following could be mentioned: (1) guiding milestones, (2) demonstrating progression, (3) illustrating function and system integration. Furthermore, it is stressed that prototyping can lead to increased engagement; help students overcome “fear of design” and help them get rid of “solution looking for problem attitude” (Schultz, 1994, p 607). According to Berglund and Leifer (2013, p. 2) working with prototypes “unlock cognitive association mechanisms related to visualisation, prior experience, and interpersonal communication in ways that favour iterative learning between peers in the product development community.” Furthermore, prototyping also gives the students chance to experiment and improve in increments, i.e. they can make a prototype, test it, and then further modify and develop the next version. This learning-by-doing approach is also connected to entrepreneurial learning, which makes such approach suitable for entrepreneurship education (see e.g. Coope, 2003 and Politis, 2005). It is important to note...
that prototyping in an educational context should be accompanied by reflection in order to turn it into a fully-fledged learning activity (c.f. Shekar 2007).

The phenomenon of prototyping has not only several functions, it has also several names, e.g. rapid prototyping, mockups and what we, in this paper, name “shitty prototyping”. Rapid prototyping is commonly connected to industrial design and engineering (see e.g. deWeck et al 2005). Furthermore, artefacts such as Lego have also been used in engineering education for prototyping in the context of mechatronics and robotics for several years (Danahy et al 2014; Gomez-de-Gabriel 2011), however use of artefacts in other types of courses is less well-known and explored.

Below we will share how we have worked with prototyping. We start with the case of Demola, which has been our role model when integrating prototyping into entrepreneurship education, and then give some examples from other courses where we have used “shitty prototyping” à la Demola. We have also used Lego for prototyping events in our courses, inspired by a workshop at the CDIO Conference in Turku in 2016.

SHITTY PROTOTYPING - THE DEMOLA WAY

Demola is an international organization that facilitates co-creation projects between university students and companies/organizations, either locally or internationally. Demola is best described as a network organization that consists of various partners including universities, companies, local agencies and a growing number of Demola centers around the globe.

Demola is also given as an 8 credit university course “Demola - Cross disciplinary project” in cooperation with Demola East Sweden and Linköping university. The student teams in the Demola course work cross-disciplinary on real-life cases together with partner companies. For instance, teams create and refine business concepts, develop new products, deal with societal problems, or build demos and prototypes. Demola course projects are (at some sites) a part of the student's degree program and the student receives credits according to the course catalog regulated individually at each partnering University. The student team owns the IPR for the results of each project. The partner company can purchase or license the student team’s creations. Partners may also want to continue the project for further development. The Demola course has been operated in collaboration with Linköping University since autumn 2012.

The Demola courses are student centered and the teams work with a high degree of independence. However, there are a few workshops included and one such workshop is named “shitty prototyping” and is run at an early stage of the course. The “shitty prototype” concept that we use in Östergotland is developed from the original Demola concept invented in Tampere, Finland. The workshop in mainly used as a tool to boost student teams’ ideation processes, viewing from the student teams’ perspective. For Demola facilitators the workshop is utilized as a way of detecting different personalities and roles within the teams, gaining an understanding of the groups dynamics and an insight of how to push the teams into new ways of approaching their challenge. After a completed workshop the facilitators are able to challenge and facilitate members within the groups individually based on their strengths, weaknesses and assumed roles. Gaining these insights is an important part of the facilitator's job to help the groups progress in their work.
Practical setup of the workshop

The workshop is run in four main blocks:

- 20 minutes of brainstorming, the wilder ideas the better!
- 30 minutes of building the prototype using craft materials and recycled junk
- 10 minutes of preparing an one minute elevator pitch that explains the prototype
- 20-30 minutes of reflection lead by the facilitator

The workshop takes place about two weeks in the course. Firstly, the participants are divided into teams with three to six participant per team (unless they haven't already been divided into Demola teams) The teams are composed to be as diverse as possible to enable as many perspectives as possible. When the brainstorming phase starts a predetermined playlist is played, design to stress and calm the teams with fast paced and mellow music. When the brainstorming phase is over the teams start building their prototypes. The material available are both conventional materials as tools, paper, tape, glue, cardboard and more unconventional materials that shift from workshop to workshop for example paper rolls, curlers and scrapyard materials.

It's very important that the facilitator is pushing the teams through each phase as teams generally tend to stretch the ideation phase. The teams should feel the right amount of stress that encourages them to not think through each idea to carefully. This forces the participant to “just throw the idea out there”, which usually stretches the limit for what is realistic and not. During the building phase the facilitator keeps asking questions about the idea and in some cases encourage the teams to go further in the development with certain ideas. The teams will most likely, during this phase, come up with new features and implementations for their ideas which is encouraged. When the building phase is completed no more additions can be made to the prototype. Now the teams shift focus to constructing a sales pitch, the pitch should be around one-minute elevator style. Here the teams can take a step back from the intense building and starts looking down on what they created. When all teams have pitched their ideas all are gathered up for questions, conclusions and rounding up.

There could also be a second part of this workshop, when time allows. Basically one or two members from each teams are rotated and the teams have a 20-minute redevelopment phase. Focus then is on creating new input to the prototypes, taking the next step and determining what is realistic and not. Doing a redevelopment phase has shown that most prototypes end up fairly close to being realistic ideas that could well be developed in a near future.

A wrap up with reflection ends each workshop where the teams reflects on their experiences both as individuals and members of a team. Typical questions that are raised: When did you feel stressed? “Was the music distracting you?” “In what phase did you feel most comfortable?” “What findings did you see from the other students with different backgrounds?” The reflections give the facilitator information where the student is the most efficient.
MOCKUPS FOR VISUALISATION IN ENTREPRENEURSHIP COURSES

Figure 2. A couple of “shitty prototypes” (1) is illustrating the hydro optic gardening system of “Vertical Garden”. The strawberries are grown indoors in hydro optic nutrition systems and supplied with LED-lightning. Through this system fresh strawberries can be produced in the neighbourhood and all year around. (Photo: Charlotte Norrman) (2) illustrates environmental problems connected to public transportation (Photo: Olof Hjelm)

Inspired by the Demola facilitators and a Lego workshop at the CDIO conference 2016 in Turku we started during the autumn of 2016 to experiment with prototyping also in other courses. A small financial contribution from Region Östergötland made it possible for us to buy Lego building blocks and craft boxes.

We have used Lego as a tool for problem visualization and needs-based idea generation during a course in Environmentally Driven Business Development (see Figure 2). In the course, Lego blocks were used to visualize problems that call for entrepreneurial solutions. We started by letting the students sit down in groups and then build and explain their individual view of a problem they have detected in the cleantech industry. Then the students merged their individual problems into a joint problem and then into a joint solution. We also used Lego in the same way in a national PhD student/practitioner course in commercialisation of biomedical engineering ideas run by Medtech4health. In this case the participants were divided into groups and their task was firstly to make an individual visualization of a healthcare related problem, and then, group wise create a joint visualization of a chosen healthcare problem.

The shitty prototype concept (facilitated as in Demola) has also been used three times in entrepreneurship courses (“Innovative Entrepreneurship”, see Figure 2 and 3, and “Entrepreneurship and new business development”).
But in difference to Demola, where the prototyping comes in at the start of a course, here it is used halfway through a course with the aim of acquiring feedback and further developing the group-work venture ideas. The prototyping was combined with a so called “Value Creation Forum” (VCF) feedback seminar - a method developed by Stanford. The seminar was arranged so that they made prototypes first and then presented them following the VCF format.

**ANALYSIS AND CONCLUSIONS**

Both Shitty prototyping and Lego prototyping is playful and prestigeless ways of visualizing product ideas, concepts and problems. It does not require technological skills, but instead opens for creativity and playfulness and thereby helps students focus on function of the idea rather than on how the prototype should be constructed technically.

In the Demola-course shitty prototyping have been used several times since the course started in 2012. The experience from the facilitator's own experiences give ahead that reflection is of high importance, e.g. it is important to sit down and discuss what parts of the shitty prototype that can be further elaborated on. Questions addressing how the problem was regarded, who is the customer/user etc are important. Through the prototyping event the students have been learned a method that can be picked up later on in the development process, and this is of high importance. The workshop shows upon the possibility to go from idea to prototype in about one hour and to know this can add confidence to the students in their development process. Another benefit is that the workshop helps strengthening the group and builds fellowship between its members, especially if the group members represent different disciplines. Finally, we have recognized that the workshop is disarming and lowers the prestige among the group members and has proved to be an important tool to track group dynamics.
Regarding the use of Lego we observed that in both cases the Lego prototyping served as tool to increase creativity. It also served as mean to let everybody in the group contribute and say what was on their minds. A third observation was that when the individual prototypes was joined together they contributed to give a more complex picture of the problem, including several dimensions. If we only had let the participants discuss, there is a risk that only the most influential ideas would have become accepted. Instead it seemed that Lego contributed to more democratic generation of results.

For the entrepreneurship courses, a preliminary evaluation shows that the prototyping events were appreciated, not least as they added a culture of playfulness and unpretentiousness to the courses. During the spring of 2017 the shitty prototyping event has been run in two courses, one with 25 students and the other with about 50 students. A small survey showed following results: in the small group (12 respondents out of 25 participants and 1,5 months after the event was run) 7% answered that the event was “very good and useful” and 83% that it was “good”. There were four alternatives for this question and no respondent selected “rather bad” or “real bad and waste of time”. In the larger group the evaluation was made directly after the event (33 respondents out of 50 participants). 45% of respondents found it “very good and useful”, 45% “good” and 9% “rather bad”.

We also asked the respondents for short comments. Here a few examples of the answers are given:

- “Good with tempo in every step - we had to focus on practice, not on thinking”
- “Nice event, an opportunity to realise both product and demo for the others”
- “There was too little time and it was stressful, otherwise good for realisation of ideas”
- “Smaller groups would be better so people stayed excited”
- “Would have prefered to have more time before for planning of one’s idea”
- “Very good to hear others’ opinions of your idea”

From this we draw the conclusion that the “Shitty prototyping” works well education contexts, it is fun and it helps the students to develop their ideas. Large groups - e.g. over 50 are not optimal as the presentations take long time and the group tends to lose energy with time. About 30 students is probably the best group size.

Comparing the different type of prototyping events, we can conclude that Lego is a fast and easy way to run a creative event. This is not least since almost every one have played with Lego when they were kids. The building blocks allow the participants to express and visualize their ideas and concretize vague thinking into concepts that can be shown to others and communicated around. On the other hand, the familiarity can act as constraint and make people “path dependent” and make them return to previous forms of creation. A drawback, especially when used by “grown ups” is that some individuals regard Lego as kid’s toys and therefore are not willing to participate. This was experienced during the MedTech course where the participants were between 25 and 70 years old.

Shitty prototyping requires more preparation and more equipment. The workshop is also more time consuming. Benefits are instead that the creation is more free than when using ready-made building blocks, such as Lego. There are no defined modules or paths to follow. For some people this stimulate creativity and for others it is a barrier. However, since the shitty prototyping is done in groups, the members can compensate weaknesses of each other and benefit from each others strengths.
Comparing with the previous studies presented above, we agree that prototyping is a good way of concretizing and illustrating ideas, as was argued by Berglund and Leifer (2003). We also agree that it aids students to overcome fear of design as proposed by Schultz (1994) as the prototyping events tend to lower prestige and promote playfulness and team spirit. Prototyping also facilitates experimentation and iteration, irrespective of what method is used. Both Shekar (2007) and the experience from Demola leads us to conclude that reflection is crucial - otherwise there is a risk that prototyping just becomes a fun event and learning opportunities are missed.

What we have realised is that engineering students are, normally, not used to creative or divergent types of teaching methods. Therefore it is important to explain carefully what will happen during a prototyping event so that students feel safe in that the teacher is in control of the overall process. Another finding that we have made, and which is interesting from a CDIO-perspective, is that especially the shitty prototyping event can be used as a tool to enhance group dynamics. During a prototyping event it is easy for a facilitator or a teacher to observe interactions and engagement in the process. Based on this knowledge groups can be coached in order to reach better group dynamics (see e.g. Schutz, 1958) and thereby also perform better.

REFERENCES


**BIOGRAPHICAL INFORMATION**

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*Marcus André* is a facilitator at Demola East Sweden, Almi East Sweden AB, responsible for facilitation of Demola teams. Marcus is responsible for the communication and collaboration with all project partners that provides cases to Demola teams.

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THE EVALUATION METHOD OF THE CDIO SYLLABUS ACHIEVEMENTS BASED ON THE EXAMINATION SCORING POINT

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College of Chemical Engineering, Beijing Institute of Petrochemical Engineering

ABSTRACT

CDIO syllabus has built a clear, complete, systematic and detailed engineering education goal. The curriculum system's design, implementation, evaluation and improvement and other links can constitute a closed-loop control system, which adjusted by constantly improvement can gradually achieve the engineering education goal of CDIO syllabus. Now the weakest link to implement this process is evaluation, which usually includes more qualitative evaluation, less quantitative evaluation, and weak correlation between the target and evaluation, or less result for curriculum system and courses, and more overall and fuzzy evaluation, or taking teachers or experts as evaluation subjects but not the students. So, in this paper the graduation standards for CDIO syllabus have been formulated, evaluation method for graduation requirement achievements based on scoring points has been proposed, evaluation system for graduation requirement achievement has been constructed, and the whole evaluation for graduation requirement achievement has been explored and practiced in automation specialty, which have achieved excellent results.

KEYWORDS

Evaluation , CDIO syllabus , Achievements , Examination , Standards:  2, 3, 11, 12

INTRODUCTION

CDIO syllabus has built a clear, complete, systematic and detailed engineering education goal. The key to achieving this goal is to design curriculum system and course outline, implement course teaching, evaluate curriculum system and teaching effect, and promote curriculum system, course outline and course teaching continuously based on the evaluation results. Thus, design, implementation, evaluation and improvement and other links can constitute a closed-loop control system, which adjusted by constantly improvement can gradually achieve the engineering education goal of CDIO syllabus. Now the weakest link to implement this process is evaluation, which usually includes more qualitative evaluation, less quantitative evaluation, and weak correlation between the target and evaluation, or less
result for curriculum system and courses, and more overall and fuzzy evaluation, or taking teachers or experts as evaluation subjects but not the students.

Recent years, in universities from all over the world, a lot of work on curriculum system and teaching effect evaluation has been done based on the ideas of "student centered" and "outcomes-based Education (OBE)", etc. Outcomes-based Education (OBE), which was first proposed by Spady [1] in 1981, has become the mainstream idea of educational reform in the United States Britain Canada and other countries. OBE has also been used as engineering education accreditation standards by American Engineering and Technical Education Accreditation Association (ABET) [2]. Vijayalakshmi M. et al [3] used evaluation criteria and matrix to achieve graduation requirements teaching performance evaluation based on the output. First, curriculum learning objectives for each course related graduate design were developed, which should be accordingly corresponding to graduation requirements. Then evaluation criteria for each teaching implementation phase was designed, based on which evaluation matrix covering all parameters of each teaching phase would be established. Using evaluation matrix, evaluation exams and teachers can calculate the reached proportion of each goal. Murray V. et al [4] attempted to drill undergraduate to do scientific research training and achieved satisfactory results. They verified the superiority of the training method by demonstrating students' engineering solutions or business plan creating technology enterprise. Guo Shiqing et al [5] put forward the achievement oriented curriculum planning model based on the concept of curriculum map. Makinda J. et al [6] proposed analytic procedure of curriculum and training program output matrix. The method was applied to the achievement evaluation of civil engineering major in University of Sabah Malaysia, the effectiveness of which was verified by multi round evaluation of different batches of students. Malaysia Institute of information technology (MIIT) developed a computer evaluation system to correlate and simplify the evaluation process of curriculum and training program output, which would promote continuous quality improvement [7]. In China, Dai Bo [8], Li Zhiyi [9] based on the discuss that reverse design should follow the principles, constructed the reverse design's process and main links, put forward the idea, strategy and key points of reverse design. Their researches focused on several key issues involved in reverse design, for example, how to determine the training objectives, graduation requirements, indicators, how to build the curriculum system, how to prepare teaching syllabus, etc., and showed the examples. Zhou, Wei et al[10] based on the discuss which knowledge and ability should be required by mechanical engineering students, improved the teaching process and assessment methods and put forward graduation requirements evaluation according to the school and social evaluation. Ou Hongxiang et al [12] on the basis of constructing and organizing graduation degree evaluation system, explored the quantitative evaluation of graduation requirements. Taking the safety engineering specialty of Changzhou University as an example, they analyzed the implementation points of achievement evaluation in professional certification process as follows: training objectives and graduation requirements, evaluation organization and personnel establishment, correspondence between curriculum system and graduation requirement, the implementation of the evaluation of greater Chengdu, etc.

The quantitative evaluation based on course examination is supposed as one of the most important evaluation methods. However, there are still some problems in the achievement calculation, as follows:

- The relationship between the achievement calculation and course assessment has not been raveled out. There are still some confusions in concepts and methods.
• The relationship between the achievement calculation of the graduates and courses has not been raveled out. The samples for calculating the two achievements are different. And the improvement effects on curriculum system and courses are different neither.
• The method achievement calculation is not perfect. Only score of course, examination and indicators were calculated, but there is still no achievement calculation method based on all course assessments.

So, in this paper the graduation standards for CDIO syllabus have been formulated, evaluation method for graduation requirement achievements based on scoring points has been proposed, evaluation system for graduation requirement achievement has been constructed, and the whole evaluation for graduation requirement achievement has been explored and practiced in automation specialty.

THE GRADUATION STANDARDS FOR CDIO SYLLABUS

CDIO syllabus covers the scientific and technical knowledge, capabilities and qualities, what should a modern engineer have. The outline is divided into four aspects: technical knowledge and reasoning ability, individual ability and occupational attitude, interpersonal skills and teamwork skills; the skills of completing the conception, design, implementation, operation for the system under the environment of enterprise and society. The syllabus consists of three levels of index system, which provides specific requirements for curriculum system and curriculum content design. For a specific professional, whose core is to cultivate the students’ ability to solve its complex engineering problems, a complete three-lever indicators system for graduation requirements can be established according to CDIO syllabus. The orientation of our school is to cultivate high-level applied talents and the educational objective of automation major is "Automation system engineer for production line". System is the main object what an automation system engineer for production line should face and serve. The system refers to automation system engineering design, automation product integration, automation engineering project implementation, automation system operation and maintenance, automation products and systems technical services, etc. So, the main complex engineering problems to be solved by production automation system engineers are engineering design, product integration, operation maintenance and technical service. Therefore, automation major takes the required engineering ability to solve the above complex engineering problems as the main line. According to four aspects of CDIO syllabus: personal expertise and engineering ability, engineering environment, personal quality, personal professional ability, 12 standards of graduation requirements and three-level index system are formulated, as described in Table 1. Personal expertise and engineering ability have 5 professional standards, which focus on developing students' professional engineering knowledge and engineering ability what are needed to solve complex engineering problems. Engineering background has 2 standards, including the social and environmental background of the project, which focuses on training students to understand the social requirements of the project, environmental constraints on the project and the impact of the project on the environment. Personal quality and personal professional ability have 5 standards, focusing on cultivating students' general engineering ability quality, which are the universal requirements for all engineering education students. Based on CDIO syllabus, 12 graduation requirements are decomposed; the three-level indicator system is formulated. The three-level indicator system of engineering knowledge for first graduation requirement will be showed in Table 2.
Table 1. Primary indicators of graduation requirements for Automation Major

<table>
<thead>
<tr>
<th>Type</th>
<th>Graduation Requirements for Automation Major</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td><strong>Engineering knowledge</strong>: be capable of solving automation system engineering design, product integration, operation maintenance and technical service complex engineering problems, using mathematics, natural science, engineering and automation expertise, and understand the current development status and trend of the automation industry</td>
</tr>
<tr>
<td>2.</td>
<td><strong>Problem analysis</strong>: be able to identify, refine, define, express, analyze, demonstrate and study automation system engineering design, product integration, operation maintenance and technical service complex engineering problems, using related knowledge, and be capable of obtaining the effective conclusion</td>
</tr>
<tr>
<td>3.</td>
<td><strong>Design solutions</strong>: synthetically considering the social, healthy, safe, legal, cultural and environmental factors, be able to design the system, components and processes for automation system engineering design, product integration, operation maintenance and technical service complex engineering problems, and can reflect the sense of innovation in the design stage</td>
</tr>
<tr>
<td>4.</td>
<td><strong>Study</strong>: be able to adopt the scientific method based on the principle to study automation system engineering design, product integration, operation maintenance and technical service complex engineering problems, the study including the design of experiments, analysis and interpretation of data, and obtaining the rational conclusion through comprehensive information</td>
</tr>
<tr>
<td>5.</td>
<td><strong>Use modern tools</strong>: in the solution of automation system engineering design, product integration, operation and maintenance, technical service of complex engineering problems, be able to design, select and use appropriate technology, resources, modern engineering tools and information technology tools for engineering practice which contains the prediction and simulation of complex engineering problems, and can understand the tools' limitations</td>
</tr>
<tr>
<td>6.</td>
<td><strong>Engineering and society</strong>: in the solution of automation system engineering design, product integration, operation and maintenance, technical service of complex engineering problems, be able to reasonably analyze the problems based on related engineering background knowledge, and can understand and evaluate the influence and responsibility of engineering practice on health, safety, law and cultural issues</td>
</tr>
<tr>
<td>7.</td>
<td><strong>Environment and sustainable development</strong>: be able to understand and evaluate the influence of engineering practice on the sustainable development of environment and society, in the practice of solving automation system engineering design, product integration, operation and maintenance, technical service of complex engineering problems</td>
</tr>
<tr>
<td>8.</td>
<td><strong>Professional norms</strong>: possess humanities and social sciences literacy, possess social responsibility, be able to understand and abide engineering ethics and codes during engineering practice, fulfill their responsibilities, have a healthy physique</td>
</tr>
<tr>
<td>9.</td>
<td><strong>Personal and teams</strong>: be able to work in a team and in a multidisciplinary environment, and understand the respective roles of individuals, team members, and supervisors</td>
</tr>
<tr>
<td>10.</td>
<td><strong>Communicate</strong>: be able to effectively communicate with the industry peers and the public on complex engineering issues in the field of automation, including writing reports, designing presentations, presenting statements, clearly expressing and responding to instructions, have a certain international perspective and foreign language communication skills, be able to communicate with others in a cross-cultural context</td>
</tr>
<tr>
<td>11.</td>
<td><strong>Project management</strong>: understand and master the basic knowledge and methods of engineering project management and economic decision, and can apply the knowledge and methods in the engineering practice under multidisciplinary environment</td>
</tr>
<tr>
<td>12.</td>
<td><strong>Lifelong learning</strong>: be aware of independent learning and lifelong learning, and be able to learn and adapt to development</td>
</tr>
</tbody>
</table>
Table 2. The three-level indicator system of engineering knowledge for first graduation requirement

<table>
<thead>
<tr>
<th>Graduation requirements (1-level index)</th>
<th>Index point (2-level index)</th>
<th>Teaching points (3-level index)</th>
</tr>
</thead>
</table>
| Engineering knowledge: be capable of solving automation system engineering design, product integration, operation maintenance and technical service complex engineering problems, using mathematics, natural science, engineering and automation expertise, and understand the current development status and trend of the automation industry | 1.1 Master mathematical abstractions, logical reasoning, mathematical calculations and modeling knowledge and capabilities to solve complex engineering problems | • Quantity, figure, space and the abstract of the relations;  
• Be capable of deductive and inductive reasoning;  
• Be capable of mathematical calculation and proof;  
• Master mathematical description, modeling and solving ability for the complicated engineering problems. |
| 1.2 Engineering knowledge and cognitive ability required for automation system engineering development | • Physics system principle cognition, experiment design and operation ability;  
• Cognition on chemistry and chemical system principle, experiment design and operation ability;  
• Cognition on mechanical device principle, structure and manufacturing;  
• Be capable of reading and designing the engineering drawing;  
• Cognition on production process flow and its principle. |
| 1.3 Automatic control system cognition and system thinking ability | 1. Establish the systematic thinking mode for systematic understanding, description, analysis of things and their interaction;  
2. Cognition on feedback control principle;  
3. Be capable of expression and analysis system structure diagram (block diagram). |
| 1.4 Computer application knowledge and calculation thinking ability in automation field; | 1. Computer principle cognition;  
2. Computational thinking ability;  
3. Computer application system software and hardware knowledge. |
| 1.5 Electronic system engineering knowledge and cognitive ability required to design, manufacture, maintain and serve the electronic automation products; | 1. Basic circuit analysis methods and basic theory;  
2. Ability of reading and understanding analog and digital electronic circuits;  
3. Cognition on common electronic components, microcontrollers, SCM, FPGA, various types of interface;  
4. The knowledge of electronic automation product development and comprehensive application. |
| 1.6 Automate engineering knowledge and cognitive ability to solve automation system engineering design, product integration, operation and maintenance, technical services and other complex engineering problems | 1. Control the principle of common process equipment;  
2. Be able to design integrated automatic control system and draw P&I diagram (pipeline instrument chart);  
3. Be familiar with products, categories and functions of automation devices and instruments (including sensors, detection components, instrumentation equipment, DCS, PLC, fieldbus, etc.);  
4. Be capable of installation, calibration, verification and cable installation for the automation devices and instruments;  
5. Be able to debug and operate automation system;  
6. Understand the engineering knowledge such as process, program requirements, quality supervision and production safety. |
| 1.7 Understand the development status and trend of automation technology and industry. | 1. Understand the development of automation technology and industry;  
2. Understand the trends of automation technology and industry. |

EVALUATION METHOD FOR GRADUATION REQUIREMENT ACHIEVEMENTS BASED ON SCORING POINTS

The relationship between achievements calculation and course evaluation

The basic data for the achievements evaluation comes from the assessment data of the basic teaching activities, that is, the assessment data of teaching points in course teaching assessment teaching assessment link, that is, the scoring points. The calculation method of achievement evaluation and course examination results are not the same but closely related. Closely relationship is that the two methods are from examine data in teaching points, namely, scoring points, where the different is the way and the goal of calculation, as shown in Figure 1. The calculation of course scoring results uses the graduation standard as a
whole goal. First, the scoring points of course examine results into examine scores, then to get overall performance. The all process is a examine of graduation standard overall goal, and no clear different of indicator points are calculated, so it leads to one course of one student correspondence to one average scores: allover scores. The calculation of achievement evaluation come from different indicator points, and the examination scoring points come from the different of achievements, so one examination step can results into some indicators of achievements, namely, one course of one student can correspond to more than one average score: different indicator points of achievements.

![Diagram of Achievement Evaluation Process](image)

**Figure 1.** The relationship between achievements calculation and course evaluation

**The computing method of the achievements for the graduation requirements**

In this paper, we present an evaluation method of graduation requirement achievements based on the examination scoring points. It first calculated the achievements of scoring points, namely, the score divide the full score, then according to the course assessment of different examination step, weighted sum calculation of indicators point results into the achievements. Lastly, weighted accumulative calculation of curriculum system results into the achievements. As shown in Figure 2. Special note that the score point should be evaluation of teaching points, and course teaching should be a decomposition of graduation standard indicators, so scoring point calculation is corresponding to the achievements of teaching points, this curriculum teaching process, curriculum design, curriculum system can effectively achieve the graduation requirements.
The computing method of the achievements for the graduation requirements is showed as follows:

**Step 1:** Formulate the index system of graduation requirements

12 graduation requirements are decomposed into graduation requirements, index points, three-lever index system for teaching points, which respectively are the teaching objectives of the curriculum system, curriculum and the three-level teaching activities in the teaching link.

**Step 2:** Establish the relationship between teaching objectives and teaching activities, and set a reasonable weight matrix

1. Establish the relationship between graduation requirements and curriculum system, and construct correlation matrix with strong correlation, general association and weak association. There are \( n \) courses to support the achievements of the \( i \)-th graduation requirements.

2. Establish the relationship between index points and curriculum system, and construct association matrix as weight. The \( i \)-th graduation requirements have \( m \) index points. The \( k \)-th course supports the achievements of the \( j \)-th index point for the \( i \)-th graduation requirements (hereafter this text will be abbreviated as "Index Point \( i,j \)"), the weight is \( W_{i,j,k} \).

3. Establish the relationship between index points and course teaching links, and construct association matrix as weight. The \( p \)-th teaching link of the \( k \)-th course supports the achievements of "Index Point \( i,j \)", the weight is \( F_{i,j,k,p} \).

4. Establish the relationship between teaching points and teaching links, and construct association matrix as weight. The \( p \)-th teaching link of the \( k \)-th course supports the achievements of the \( r \)-th teaching points for "Index Point \( i,j \)", the weight is \( R_{i,j,r,k,p} \).
Step 3: Taking teaching key points as the goal, establish the evaluation standard of teaching link and calculate the achievements of sample students' teaching points

Based on the achievements of teaching points, develop assessment criteria for teaching link assessment, and get the ratio of examination results for teaching points in teaching links obtained by sample students to full marks. The p-th teaching link of the k-th course supports the achievements of the r-th teaching points for "Index Point i,j", whose proportion to full marks is \( S_{i,j,r,k,p} \), that is, sample students' teaching achievement.

Step 4: Calculate the achievements of index points for sample students' courses, with index points as the goal

Based on the achievements of teaching points in teaching links, calculate the achievements of index points for sample students' courses, according to the relationship between teaching points and teaching links, the relationship between index points and teaching links, and the corresponding weight coefficients.

1. Calculate the achievements of index points for teaching and assessment link. The p-th teaching link of the k-th course supports the achievements of the r-th teaching points for "Index Point i,j", whose proportion to full marks is \( S_{i,j,r,k,p} \). Weighted add up the proportions which the p-th teaching link of the k-th course supports the achievements of all teaching points for "Index Point i,j", so the achievements of "Index Point i,j" for the p-th teaching link obtained by sample students' is \( H_{i,j,k,p} \), the calculation as shown in the form Eqn (1).

\[
H_{i,j,k,p} = \sum_{r} \left( R_{i,j,r,k,p} \cdot S_{i,j,r,k,p} \right) \tag{1}
\]

2. Calculate the achievements of index points for the curriculum. Weighted add up the achievements of all teaching points for "Index Point i,j" for the k-th course, so the achievements of "Index Point i,j" for k-th course obtained by sample students' is \( C_{i,j,k} \), the calculation as shown in the form Eqn (2).

\[
C_{i,j,k} = \sum_{p} \left( F_{i,j,k,p} \cdot H_{i,j,k,p} \right) \tag{2}
\]

Step 5: Calculate the achievements of index points for sample students' curriculum system, with index points as the goal

Weighted add up the achievements of "Index Point i,j" for all courses, so the achievements of "Index Point i,j" for curriculum system obtained by sample students' is \( I_{i,j} \), the calculation as shown in the form Eqn (3).

\[
I_{i,j} = \sum_{k} \left( W_{i,j,k} \cdot C_{i,j,k} \right) \tag{3}
\]

Step 6: Calculate the achievements of graduation requirements for sample students’ curriculum system, with graduation requirements as the goal
Take the minimum in all achievements of index points for i-th graduation requirements as the achievement for i-th graduation requirements, so the achievement of graduation requirements obtained by sample students is $A_i$, the calculation as shown in the form Eqn (4).

$$A_i = \min_j \left(I_{i,j}\right)$$

**EVALUATION SYSTEM FOR GRADUATION REQUIREMENT ACHIEVEMENT**

To implement the achievement evaluation of graduation requirements, we constructed a standard evaluation system to decompose graduation requirements, design the teaching activities, calculate teaching activities achievements, continuously improve the teaching activities and show an evaluation mechanism of self-evaluation. The evaluation process and system is shown in Figure 3. Two objects of achievements are graduates and courses. If the object is a undergraduate, the evaluation results from the teaching activity of training scheme, namely the graduate's curriculum system, course, teaching evaluation of learning outcomes, and the goal is to evaluate achievement of graduation requirements. If the object is a course, the evaluation results from the teaching effect of graduation requirements. And the goal is to evaluate achievement of course teaching.

![Figure 3. The evaluation system of the achievements for graduation requirements](image)

The graduation requirements of automation major are decomposed into graduation standard, index point, teaching points based on CDIO syllabus, and these indicate the teaching goal of three hierarchical teaching activities including the curriculum system, courses and teaching programs. The design results of these three hierarchical teaching activities are specialty cultivation plan (curriculum system), course outline, teaching program and assessment scoring standard. The achievement evaluation of graduation requirements initiates from the assessment data representing the achievement of key points by means of the teaching program. Then the recurrent calculation takes place. According to the data of calculation process, continuous improvements on curriculum system integration, course teaching reform, teaching program and assessment have been implemented. The self-assessment of
evaluation mechanism is to take place based on the judgment of whether or not it is reasonable to form the evaluation standard, whether or not the system establishment is complete, whether or not the method designation is scientific, whether or not the step is done in place, whether or not the results are reasonable, whether or not the standard has been used in continuous improvement, etc.

**CALCULATION FOR GRADUATION REQUIREMENT ACHIEVEMENT**

*Reversely design curriculum system with graduation requirements as the goal*

The professional graduation requirement is achieved by the reverse design of a reasonable curriculum system, and the curriculum system for graduation requirement is supported by implementing each course. The graduation requirement achievement is realized by the relationship between the curriculum and graduation requirement index points. The graduation requirement is carried out according to the index points, and the relationship between graduation requirement indexes and curriculum is established by matrix. The correlation degree is expressed by weight coefficient Wi.j.k. The strong correlation set the weight coefficient which is greater than 0.5, the general correlation set the weight coefficient which is 0.2--0.4, the weight coefficient is 0.1 set for the weak correlation. The sum of the weight coefficients for all support courses which are corresponding to each graduation requirement index point must be 1.

*Design the curriculum syllabus with index points as the goal*

We refine course teaching, design course teaching link and establish index point and course teaching link relation. Each course teaching and assessment links should be refined. Course content, teaching method and examination methods should be designed. The curriculum syllabus is carried out according to the graduation requirements index points, and the relationship between graduation requirement indexes and course teaching and assessment link is established by matrix. The correlation degree is expressed by weight coefficient Fi.j,k,p. The strong correlation set the weight coefficient which is greater than 0.5, the general correlation set the weight coefficient which is 0.2--0.4, the weight coefficient is 0.1 set for the weak correlation. The sum of the weight coefficients for all support courses which are corresponding to each graduation requirement index point must be 1. The relationship between graduation requirements index points and curriculum teaching and assessment links for Electronic Engineering Design will be shown in Table 3.
Table 3. The relationship between graduation requirements index points and curriculum teaching and assessment links for Electronic Engineering Design

<table>
<thead>
<tr>
<th>Graduation requirements</th>
<th>Electronic Engineering Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>Electronic system engineering knowledge and cognitive ability for design, manufacture, maintenance and service of electronic automation products</td>
</tr>
<tr>
<td>2.2</td>
<td>Analysis capability for function, structure and system of electronic automation products</td>
</tr>
<tr>
<td>3.2</td>
<td>Be able to design electronic engineering systems and automation product with the awareness of health, safety, environment</td>
</tr>
<tr>
<td>5.1</td>
<td>Be able to make, debug and test the commonly used electronic instruments and automation equipment</td>
</tr>
<tr>
<td>9.1</td>
<td>Correctly understand the relationships between individuals and teams under the multidisciplinary environment, and develop effective teams</td>
</tr>
<tr>
<td>9.3</td>
<td>Understand the role of team members and head, be capable of certain team leadership skills</td>
</tr>
<tr>
<td>10.2</td>
<td>Be capable of written and graphic communication, oral and personal communication, electronic and multimedia communications with industry peers and the public on complex engineering problems in automation</td>
</tr>
<tr>
<td>11.1</td>
<td>Understand project's time and cost management, quality and risk management, and human resource management, and apply these to multidisciplinary environmental engineering practice</td>
</tr>
</tbody>
</table>

| Weight coefficient of index points | 0.1 | 0.2 | 0.3 | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 1.5 |
| Weight coefficient of teaching and assessment links | 1 | 0.1 | 0.1 | 0.2 | 0.1 | | 1 | 0.1 | 1 |

Design assess criteria in teaching link with teaching points as the goal

Course teaching link implements teaching based on the relevant teaching points of relevant index points. The realization of teaching points determines the teaching quality of relevant teaching links. So we reasonably design teaching links based on the teaching points of each course’s related index points, check the teaching links with the realization of teaching points, formulate the teaching link assessment scoring standards with teaching points achievement as the assessment target. Teaching points score divided by setting out is the teaching points achievement. The assessment scoring standards of examination teaching and teaching links for Electronic Engineering Design will be shown in Table 4.
Table 4. The assessment scoring standards of examination teaching and teaching links for Electronic Engineering Design

<table>
<thead>
<tr>
<th>Serial</th>
<th>Teaching and examination</th>
<th>Weight</th>
<th>Scoring criteria (50 points)</th>
<th>Score</th>
<th>teaching points achievement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.5-4 Electronic</td>
<td>10%</td>
<td>2 fill-in-the-blanks exercises are set, each question accounts for 2 points, there are altogether 4 points. Assessment for basic theory of electronic circuits, analog electronic and digital electronics, basic concepts of electronic engineering design.</td>
<td></td>
<td>Score / Full mark</td>
</tr>
<tr>
<td></td>
<td>automation product</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>development and its</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td>integrated application</td>
<td></td>
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<tr>
<td></td>
<td>knowledge</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3.2-1 Electronic</td>
<td>5%</td>
<td>1 fill-in-the-blanks exercises is set, each question accounts for 2 points, there are altogether 2 points. Assessment for composition of temperature measurement control system and the function of each part.</td>
<td></td>
<td>Score / Full mark</td>
</tr>
<tr>
<td></td>
<td>system structure design</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3.2-2 Hardware and</td>
<td>45%</td>
<td>2 fill-in-the-blanks exercises are set, each question accounts for 2 points, 2 analytical questions are set, each question accounts for 10 points, there are altogether 20 points, there are altogether 4 points. Assessment for the design, function and composition for regulated power supply module, signal conditioning module, A/D module, D/A module, control module, keyboard and display module.</td>
<td></td>
<td>Score / Full mark</td>
</tr>
<tr>
<td></td>
<td>software design for</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>analog and digital circuit</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>5.1-1 Selection of</td>
<td>12%</td>
<td>3 fill-in-the-blanks exercises are set, each question accounts for 2 points, there are altogether 6 points. Assessment for use knowledge of resistors, capacitors, inductors and other basic components</td>
<td></td>
<td>Score / Full mark</td>
</tr>
<tr>
<td></td>
<td>electronic components</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>and common use of</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>common instruments</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5.1-2 Design, fabrication,</td>
<td>8%</td>
<td>2 fill-in-the-blanks exercises are set, each question accounts for 2 points, there are altogether 4 points. Assessment for the application of PROTEL software and welding of printed circuit board.</td>
<td></td>
<td>Score / Full mark</td>
</tr>
<tr>
<td></td>
<td>welding and</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>commissioning for PCB</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>9.3-1 Correctly</td>
<td>10%</td>
<td>1 short answer question is set, there is altogether 5 points. Choose one from 6 and 7. Assessment for the understanding for the basic concepts of individuals and teams (such as team definition, team formation and lifecycle).</td>
<td></td>
<td>Score / Full mark</td>
</tr>
<tr>
<td></td>
<td>understand the role and</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>responsibility of team</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>members and head</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>9.3-2 Clear the team's</td>
<td>10%</td>
<td>1 short answer question is set, there is altogether 5 points. Choose one from 6 and 7. Assessment for the understanding for the role of team members and how to better implement the role of rationalization proposals.</td>
<td></td>
<td>Score / Full mark</td>
</tr>
<tr>
<td></td>
<td>overall and specific</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>objectives, reasonably</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>make work plan</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>11.2-1 Project specific</td>
<td>10%</td>
<td>1 short answer question is set, there is altogether 5 points. Choose one from 8 and 9. Assessment for how to understand the basic concepts of project management (e.g. scheduling, time control, etc.)</td>
<td></td>
<td>Score / Full mark</td>
</tr>
<tr>
<td></td>
<td>activities defined,</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>activity sequencing,</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>time estimating, schedule</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>and time control</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>11.2-2 Resource allocation,</td>
<td>10%</td>
<td>1 short answer question is set, there is altogether 5 points. Choose one from 8 and 9. Assessment for how to understand the basic concepts of project management (e.g. resource allocation, quality and risk management, etc.)</td>
<td></td>
<td>Score / Full mark</td>
</tr>
<tr>
<td></td>
<td>cost, expense budget and</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>cost control for the project</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Calculate graduation requirements achievement**

We should calculate graduation requirements achievement from the teaching link assessment data of all courses of for the graduates. We should hierarchically and gradually calculate graduation requirements achievement, according to the relationship between teaching links and teaching points, courses and index points, curriculum system and index points, curriculum system and graduation requirements. The calculation steps are shown in Figure 4.
Figure 4. Calculation of graduation requirements achievement for teaching activities

The calculation of the index point achievements for the course is shown in Table 5.
### Table 5. Calculation of the index point achievements for Electronic Engineering Design

<table>
<thead>
<tr>
<th>Graduation Requirements</th>
<th>Index point</th>
<th>Electronic Engineering Design</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.5</td>
<td>Electronic system engineering knowledge and cognitive ability for design, manufacture, maintenance and service of electronic automation products</td>
</tr>
<tr>
<td></td>
<td>2.2</td>
<td>Analysis ability for function, structure and system of electronic automation products</td>
</tr>
<tr>
<td></td>
<td>3.2</td>
<td>Be able to design electronic engineering systems and automation product with the awareness of health, safety, environment</td>
</tr>
<tr>
<td></td>
<td>5.1</td>
<td>Be able to make, debug and test the commonly used electronic instruments and electronic automation product</td>
</tr>
<tr>
<td></td>
<td>9.1</td>
<td>Correctly understand the relationship between individuals and teams under the multidisciplinary environment and develop effective teams</td>
</tr>
<tr>
<td></td>
<td>9.3</td>
<td>Understand the role of team member and head, be capable of certain leadership skills</td>
</tr>
<tr>
<td></td>
<td>10.2</td>
<td>Be capable of written and graphic communication, oral and personal communication, electronic and multimedia communications with industry peers and the public on complex engineering problems in automation</td>
</tr>
<tr>
<td></td>
<td>11.1</td>
<td>Understand project's time and cost management, quality and risk management, and human resource management, and apply these to multidisciplinary environmental engineering practice</td>
</tr>
</tbody>
</table>

| Weight coefficient of index points | 0.1 | 0.2 | 0.3 | 0.3 | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 1.5 |

<table>
<thead>
<tr>
<th>Teaching and assessment links</th>
<th>The index point achievements of teaching and assessment links / weight coefficient</th>
<th>Course grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commonly use of electronic equipment and basic experimental operation</td>
<td>0.05</td>
<td>0.87</td>
</tr>
<tr>
<td>Hardware</td>
<td>0.6</td>
<td>0.80</td>
</tr>
</tbody>
</table>
The index point achievement of each graduate’s curriculum system is shown in Table 6.

### Table 6. Calculation table for the achievement of index point 3.3

<table>
<thead>
<tr>
<th>Number</th>
<th>Index i.j</th>
<th>3.3 Be capable of configuration, software design and debugging for PLC, DCS, FCS control system</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Course</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Principle and application A of DCS/PLC/FCS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Principle and application B of DCS/PLC/FCS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Index point achievement of curriculum system</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$W_{ij,k}$</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>12</td>
<td>Wang XN</td>
<td>0.56</td>
</tr>
<tr>
<td>13</td>
<td>Zhang Yu</td>
<td>0.78</td>
</tr>
<tr>
<td>14</td>
<td>Li GL</td>
<td>0.74</td>
</tr>
<tr>
<td>15</td>
<td>Liang ZW</td>
<td>0.53</td>
</tr>
<tr>
<td>16</td>
<td>Zhang RP</td>
<td>0.69</td>
</tr>
<tr>
<td>17</td>
<td>Hong TZ</td>
<td>0.89</td>
</tr>
<tr>
<td>18</td>
<td>Wang QS</td>
<td>0.70</td>
</tr>
<tr>
<td>19</td>
<td>Liu ZY</td>
<td>0.64</td>
</tr>
<tr>
<td>20</td>
<td>Wang XL</td>
<td>0.84</td>
</tr>
<tr>
<td>21</td>
<td>Zhang AK</td>
<td>0.64</td>
</tr>
<tr>
<td>22</td>
<td>Zhang Hao</td>
<td>0.69</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>2015 session’s average</td>
<td></td>
<td>0.71</td>
</tr>
</tbody>
</table>

Graduation requirements achievement for each graduate’s curriculum system is shown in Table 7.

### Table 7. Calculation table for the achievement of graduation requirement 3.3

<table>
<thead>
<tr>
<th>Number</th>
<th>Graduation Requirement i.j</th>
<th>3.1 The ability of designing, programming and debugging computer programming (Achievement)</th>
<th>3.2 Be able to design electronic engineering systems and automation products with the health, safety, environmental awareness (Achievement)</th>
<th>3.3 Be capable of configuration, software design and debugging for PLC, DCS, FCS control system (Achievement)</th>
<th>3.4 Be able to design and integrate automatic control system engineering with health, safety and environmental awareness (Achievement)</th>
<th>The graduation requirements achievement for curriculum system A_i</th>
</tr>
</thead>
<tbody>
<tr>
<td>...</td>
<td></td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>12</td>
<td>Wang XN</td>
<td>0.83</td>
<td>0.76</td>
<td>0.78</td>
<td>0.73</td>
<td>0.73</td>
</tr>
<tr>
<td>13</td>
<td>Zhang Yu</td>
<td>0.76</td>
<td>0.80</td>
<td>0.89</td>
<td>0.81</td>
<td>0.76</td>
</tr>
<tr>
<td>14</td>
<td>Li GL</td>
<td>0.75</td>
<td>0.84</td>
<td>0.87</td>
<td>0.81</td>
<td>0.75</td>
</tr>
<tr>
<td>15</td>
<td>Liang ZW</td>
<td>0.72</td>
<td>0.86</td>
<td>0.76</td>
<td>0.82</td>
<td>0.72</td>
</tr>
<tr>
<td>16</td>
<td>Zhang RP</td>
<td>0.83</td>
<td>0.79</td>
<td>0.85</td>
<td>0.75</td>
<td>0.75</td>
</tr>
<tr>
<td>17</td>
<td>Hong TZ</td>
<td>0.69</td>
<td>0.94</td>
<td>0.84</td>
<td>0.69</td>
<td>0.69</td>
</tr>
<tr>
<td>18</td>
<td>Wang QS</td>
<td>0.71</td>
<td>0.78</td>
<td>0.85</td>
<td>0.78</td>
<td>0.71</td>
</tr>
<tr>
<td>19</td>
<td>Liu ZY</td>
<td>0.70</td>
<td>0.78</td>
<td>0.82</td>
<td>0.78</td>
<td>0.70</td>
</tr>
<tr>
<td>20</td>
<td>Wang XL</td>
<td>0.91</td>
<td>0.92</td>
<td>0.92</td>
<td>0.86</td>
<td>0.86</td>
</tr>
<tr>
<td>21</td>
<td>Zhang AK</td>
<td>0.75</td>
<td>0.79</td>
<td>0.82</td>
<td>0.71</td>
<td>0.71</td>
</tr>
<tr>
<td>22</td>
<td>Zhang Hao</td>
<td>0.75</td>
<td>0.84</td>
<td>0.84</td>
<td>0.83</td>
<td>0.75</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>2015 session’s average</td>
<td></td>
<td>0.82</td>
<td>0.78</td>
<td>0.78</td>
<td>0.78</td>
<td>0.78</td>
</tr>
</tbody>
</table>
**Analyze the graduation requirements achievement**

The calculation of the most recent (2015) graduates' graduation requirements achievement is shown in Table 8.

### Table 8. Calculation for the achievement of graduation requirement 2

<table>
<thead>
<tr>
<th>Index i,j</th>
<th>Compulsory Course k</th>
<th>weight coefficient $W_{i,j}$</th>
<th>Assessment Methods</th>
<th>Achievement’s evaluation period</th>
<th>Evaluation result of index point achievement</th>
<th>Evaluation result of graduation requirements achievement</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Advanced mathematics</td>
<td>0.1</td>
<td>Process assessment + experimental examination + group assessment + final exam</td>
<td>4 years or 1 year</td>
<td>0.78</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>College Physics</td>
<td>0.2</td>
<td></td>
<td></td>
<td>0.83</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>College Physics Experiment</td>
<td>0.1</td>
<td></td>
<td></td>
<td>0.80</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>Complex function and integral transformation</td>
<td>0.1</td>
<td></td>
<td></td>
<td>0.73</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>Chemical Engineering Foundation</td>
<td>0.2</td>
<td></td>
<td></td>
<td>0.79</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>Weight accumulation</td>
<td>0.7</td>
<td></td>
<td></td>
<td>0.79</td>
<td>0.79</td>
</tr>
<tr>
<td>2.2</td>
<td>Circuit analysis A</td>
<td>0.1</td>
<td>Process assessment + experimental examination + group assessment + final exam + defense</td>
<td>4 years or 1 year</td>
<td>0.80</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>Analog Electronic Technology</td>
<td>0.1</td>
<td></td>
<td></td>
<td>0.83</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>Digital electronic technology</td>
<td>0.1</td>
<td></td>
<td></td>
<td>0.77</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>Electronic engineering design</td>
<td>0.2</td>
<td></td>
<td></td>
<td>0.83</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>Microcomputer principle and interface technology</td>
<td>0.1</td>
<td></td>
<td></td>
<td>0.83</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>Single chip microcomputer engineering practice</td>
<td>0.1</td>
<td></td>
<td></td>
<td>0.76</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>Embedded system and its application</td>
<td>0.1</td>
<td></td>
<td></td>
<td>0.86</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>Testing technology and instruments</td>
<td>0.1</td>
<td></td>
<td></td>
<td>0.82</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>Instrument technology professional practice</td>
<td>0.1</td>
<td></td>
<td></td>
<td>0.82</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>Weight accumulation</td>
<td>0.7</td>
<td></td>
<td></td>
<td>0.81</td>
<td>0.81</td>
</tr>
<tr>
<td>2.3</td>
<td>Automatic control principle A</td>
<td>0.4</td>
<td>Process assessment + experimental examination + group assessment + final exam + defense</td>
<td>4 years or 1 year</td>
<td>0.73</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>Modern control theory</td>
<td>0.4</td>
<td></td>
<td></td>
<td>0.85</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>Integrated design of control system</td>
<td>0.1</td>
<td></td>
<td></td>
<td>0.80</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>Advanced control technology</td>
<td>0.1</td>
<td></td>
<td></td>
<td>0.80</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>Weight accumulation</td>
<td>1</td>
<td></td>
<td></td>
<td>0.79</td>
<td>0.79</td>
</tr>
<tr>
<td>2.4</td>
<td>Single chip microcomputer engineering practice</td>
<td>0.2</td>
<td>Process assessment + experimental examination + group assessment + final exam + defense</td>
<td>4 years or 1 year</td>
<td>0.67</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>The principle and application of DCS/PLC/FCS B</td>
<td>0.1</td>
<td></td>
<td></td>
<td>0.65</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>Science and Technology Writing</td>
<td>0.3</td>
<td></td>
<td></td>
<td>0.71</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>The computer process control engineering B</td>
<td>0.1</td>
<td></td>
<td></td>
<td>0.86</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>Graduation project (Thesis)</td>
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<td></td>
<td></td>
<td>0.80</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>Weight accumulation</td>
<td>1</td>
<td></td>
<td></td>
<td>0.74</td>
<td>0.74</td>
</tr>
</tbody>
</table>

The calculation for graduation requirements achievement is quantitative evaluation for whether the learning output of the teaching activities meets the graduation requirements. The purpose of evaluation is to continuously improve students' teaching activities. Therefore, based on the calculation for graduation requirements achievement, we improve the professional teaching activities on the formulation of the graduation requirements index system, curriculum integration and curriculum teaching reform.
CONCLUSION

The evaluation method for graduation requirements achievement is explored and put into practice. Be applied to graduates, the method can evaluate whether the professional graduates meet the quality standards set by graduation requirements, analyze and find the weak items of which the professional graduates meet the quality standards set by graduation requirements. Accordingly, our major can promote the continuous improvement of teaching activities to ensure that the graduates can achieve the professional graduation requirements. Be applied to curriculum, the method can evaluate the graduation requirements achievement for course teaching, analyze and find the weak items of which the course teaching meet the quality standards set by graduation requirements. Accordingly, our major also can promote the continuous improvement of teaching activities. The method has been applied to Automation engineering professional education certification in our school, which has achieved very good results.

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**Bo Lan** is an associate professor and dean of electrical and electronic teaching and experiment center at Beijing Institute of Petrochemical Engineering. He taught the course of electrical and electronic technology.

**Teng Wang** is an associate professor of pharmaceutical engineering department and Deputy director of academic affairs office at Beijing Institute of Petrochemical Engineering. He taught the course of pharmaceutical technology.

**Zhansheng Han** is a professor of chemical engineering department and vice-president for academic affairs at Beijing Institute of Petrochemical Engineering. His current research focuses on engineering education reform and on curriculum development methodology.

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FORMING EFFECTIVE CULTURALLY DIVERSE WORK TEAMS IN PROJECT COURSES

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ABSTRACT

A culturally diverse student population at Master's level is a reality at many universities today, as it is at Chalmers University of Technology in Sweden. However, a common issue is the lack of interaction between home and international students, which counteracts university goals of fostering intercultural cooperation.

This paper will discuss and evaluate a pilot project in one Master's program in production engineering, where activities around group diversity were integrated into a company-based project course. Students were assigned groups where a mixture of backgrounds and expertise were prioritised.

The project used a number of group dynamics activities including a pre-survey of expectations of group work; negotiating a group contract; and continuous peer group assessment in order to develop and reflect on the skills required in a culturally diverse work team.

From reflective essays that students wrote, as well as interviews carried out, the project and tasks were evaluated. The following themes were identified: attitudes to diversity; the importance of well-functioning communication; and attitudes and roles within the group. Results show that students found this a challenging but useful environment to work in and found the group dynamics activities helpful in negotiating this environment. Continuous peer group assessment, in particular, was seen as helpful in providing a forum for feedback and discussion on individual performance in the group and challenges for the group as a whole. Recommendations include constructive alignment within the program in terms of clear goals, activities and assessment, in order to build up these skills and awareness, not only in a single course but throughout the program.

KEYWORDS

Culturally diverse groups, project courses, team-member assessment, Standards 3,7,8
INTRODUCTION

Many universities are international environments with mixed student populations. In response to this, there has been much discussion about how to create a useful working environment to utilise this diversity (Carroll and Ryan, 2007; Leask, 2015; Ryan, 2013). Some of the examples that have been presented at CDIO conferences are improved introductions to Master programs for international students (Knutson Wedel, 2010), intercultural training for students (Josefsson, 2010) and a global village (Gourvès-Hayward, Morace, & Rouvrais, 2013).

This article presents and reflects upon an integrated course based solution where students receive training and support in their diverse groups in order to improve both the work process and mutual understanding. As supported in the references given above, both home and international students need skills in diverse teamwork and intercultural communication (see CDIO syllabus items 2.4.2, 2.5.2, 2.5.5, 3.1.1, 3.2.2, 3.2.10 and 4.1.6). Therefore, we argue that by integrating such activities into existing courses, all students can benefit, not just in terms of more successful group work, but also in aiding better mutual understanding on campus.

INTEGRATING HOME AND INTERNATIONAL STUDENTS IN GROUP WORK

Minimal interaction between home and international students on campus is a well-documented issue (De Vita 2002; Gourvès-Hayward, Morace and Rouvrais, 2013; Knutson Wedel and Persson, 2010; Leask 2009; Summers and Volet 2008) and is similarly the case at Chalmers University of Technology where a survey we conducted in 2015 showed issues with classroom interaction. This lack of interaction is understandable in some ways; since international students join the education in the fourth year of studies in Sweden (at Master’s level, the language of education changes to English), the Swedish students have already had three years to get acquainted, and by Master’s level, students are typically very focused on completing their education.

Though understandable, this lack of interaction is problematic from a university, company and CDIO perspective. From a university perspective, diversity has been lifted as a core value at Chalmers and there are clear goals connected to cooperation, including that “The learning environment must foster intercultural cooperation” (Chalmers University of Technology, 2016). From a company perspective, companies are striving towards a diverse workforce (see, for example, www.volvogroup.com) and it is an advantage if a student can demonstrate this experience. From a CDIO perspective, there are particular syllabus items which refer to working in diverse groups, where the importance of engaging and connecting with diverse individuals is stressed. Thus, this interaction needs to be encouraged at Master’s level and this focus is similarly reflected in the same policy document mentioned above at Chalmers: “Create global perspectives by setting learning targets for insights related to norms, attitudes and values in all Master’s programmes” (Chalmers internal policy document, 2016).

There are a number of ways of encouraging interaction between different student groups, both within formal and informal curricula (Gourves-Hayward et al, 2013; Knutson Wedel and Persson 2010; Leask 2009). The initiative described in this article focuses on group work within courses for a number of reasons. Firstly, project work in groups is a key aspect of engineering education at Chalmers and elsewhere, partly due to the fact that the ability to
work in groups has been seen to be crucial at company level. Secondly, interviews carried out with international Master’s students from a range of cultural backgrounds at Chalmers have shown that this is one aspect of Swedish education which they react to as being different. Thirdly, group work is an ideal opportunity for intercultural cooperation to take place (Leask 2009; Summers and Volet 2008).

However, there are a number of issues with working in mixed groups. Diverse groups can experience more conflict (Ayoko, 2007) and home students are not always positive to being mixed (Summers and Volet, 2008), believing that it can have a detrimental effect on their grades (De Vita, 2002). Leask (2009) argues that it is essential to consider constructive alignment in the course from an intercultural perspective as well, such that relevant intercultural learning objectives are included in the course goals and assessment activities take into account the intercultural competencies. She also argues that the purpose and value of the interaction need to be understood; that students need to be assisted to develop the skills they need to engage with each other; that they should be provided with the opportunities they need to engage effectively, and that they should be rewarded appropriately for their achievements.

This article discusses one pilot project course at Chalmers where students worked in culturally mixed groups. In this course, intercultural interventions were adopted to support them in this process. The article will both describe and evaluate these interventions, and discuss whether these can provide a way forward in working with diverse teams and meeting the CDIO goals.

**PILOT PROJECT COURSE: PPU171 INDUSTRY PROJECT**

PPU171 Industry Project is a 7.5 credit course given over nine weeks as an optional course for students in their final year of M.Sc. studies at Chalmers University of Technology, just before they start doing their Master’s theses. Prior to this course, most of the students have worked in groups to solve a given task in other courses, making use of, for example, group contracts. Despite this experience, issues with group dynamics and teamwork have been raised in PPU171 as the students have had issues working together. The purpose of the course is for students to learn how to solve real industrial problems by applying previously learnt established engineering methods, work in teams and effectively communicate to various stakeholders through active collaboration in a project group. Some of the key learning objectives of the course are:

- Formulate a clear problem and create a project plan
- Assess engineering solutions from the perspective of sustainable development, with consideration to both scientific and ethical aspects
- Work in project teams and analyze the project work in terms of group dynamics
- Develop project results following an established project methodology
- Write a technical report that follows an established structure and policies of academic honesty

One student commented that: “This project is different from other projects. Projects engaged previously were well constrained by the course content and leaded by the same examiner. This project is totally different” (Asian student)
Out of the 31 students who elected to take the course, 17 were international students, mostly from India, but also from China, Greece, the Netherlands, Lebanon and other countries in Asia, Europe and Africa. The international students had a Bachelor's degree in an engineering discipline from another country, while all Swedish students had a Bachelor's degree in engineering from Chalmers University of Technology. All of the students were from the same Master's programme, Production Engineering; however, there was some diversity in the elective courses they had taken, ranging from Simulation of Production Systems, and Change Management and Improvement Processes to Metal Cutting, and Robotics and Manufacturing Automation.

The Swedish students received a lot of input and experience regarding group dynamics and working in groups in their Bachelor program, while most of the international students had very limited experience with group work, apart from as part of the other electives they took on the Master’s program. The 17 international students were divided into six groups together with the 14 Swedish students based on each student’s previously taken courses to ensure that all groups were multicultural and had a diverse skill-set. The additional course the students took alongside this course was also factored in to create groups that had similar schedules. Each group contained approximately five students.

The groups were given a real, vaguely defined industry problem, a supervisor from the respective company as well as a supervisor from the university along with some guidance in how to conduct their projects and how to create a project plan. Each group had a meeting with their supervisors the first day and started working on defining and specifying precisely the problem they intended to solve during the course right away, as the given problem was too broad and vague to realistically be fully solved in only nine weeks of half-time work.

In terms of support, the students received supervision from both the industry and the university, and input on project planning and presentation techniques as well as the group diversity sessions described below. The assessment of the course is based on the following elements: the project report, an individual presentation, a peer evaluation where each student grades themselves and their project colleagues, and an optional reflection hand-in regarding group dynamics.

GROUP DIVERSITY SESSIONS

Within the overall course setup, two teachers from the Division for Language and Communication at Chalmers helped facilitate team-formation [CDIO 3.1.1] and group processes. Previous runs of the course had included some group dynamics input, with students working through group contracts, team member - and self - assessment criteria, and a reflection at the end of the process. The new changes in the course aimed to develop these existing activities by introducing aspects of intercultural communication in order to encourage students to take a broader perspective [CDIO 4.16] when agreeing on ways of working within their team [CDIO 2.5.2], and accommodating diverse educational and cultural backgrounds [CDIO 2.5.5]. This took the form of a seminar early in the project, individual group meetings in the middle of the project and a final half-class seminar at the end of the course. During the process, this broader perspective was linked to students’ work with group contracts, the team-member assessment, and other activities.
Activities

Seminar input covered aspects of intercultural communication and diversity, primarily aimed at promoting the discussion of various, differing viewpoints (CDIO 2.4.2) and on raising awareness (CDIO 4.1.6). However, the main focus was to work with the students in a hands-on way, in a number of different activities.

Group Diversity Survey

The students had completed a survey prior to the first seminar, and this was used as a starting point for discussions of values, openness, diversity, and views on how groups and individuals should act to promote teamwork. For example, the survey showed that all students strongly agreed on the importance of ‘showing respect’; however, their views on ‘respect’ differed, and they were given the opportunity to discuss what respect and other similar terms mean, with the aim of agreeing upon ways of showing respect within their group, which could then be incorporated into their group contract.

SWOT Analysis

Another activity used to facilitate the writing of a group contract was a modified SWOT analysis (in this case, Strengths, Weaknesses, Opportunities, and Fears), which prompted the students to reflect individually on the group, before further in-group discussions. The premise was that in reflecting on strengths and weaknesses, students would be better equipped to understand their own potential role and contribution within the group. Discussing opportunities encouraged the students to work with their initial impressions of the team-members, and explore ways of utilizing the broad range of backgrounds and competencies. Finally, the students reflected on fears in order to anticipate potential problems, and discuss ways of either avoiding crisis situations, or resolving them when they arise.

Group Contract

Both the survey and SWOT analysis facilitated the writing of a group contract. The group contract consisted of four broad areas – meetings, tasks, attitudes, and group issues – with prompts and suggestions for possibly relevant discussion points. The students had significant freedom in the length, focus, and attention to detail in the contract; they were encouraged to take a broader perspective, where possible, by discussing what the contract actually meant to them. This involved unpacking key terms and agreeing on what they would mean to the group. For example, can they agree upon ways of showing respect in a meeting? Is coming to meetings on time something which the group values? In working in this way, the students were required to exchange cultural information, directed in a meaningful way to the task at hand, which Leask (2009, p. 211) argues is “central to improving the interactions between international and home students.”

Team Member Assessment

Another activity, used primarily to facilitate discussion and feedback within groups, and to a lesser extent for assessment, was the team-member assessment. Each student assessed themselves, and each member in the group, based on a set of criteria with a 5-point Likert scale, covering six main areas. The decision was made to modify the existing team-member assessment from previous years, rather than develop a new assessment, as the focus was on developing an integrated, course-based solution. Although Likert-scale assessment tools
for intercultural competence have been criticized (Dervin, 2010), the criteria was used primarily to generate discussion rather than for assessment, which partially overcomes some of those criticisms. Additionally, the criteria had a focus on group dynamics, rather than cultural competence; it was the students’ task to interpret and work with the criteria from a broader perspective. The criteria were revised throughout the process, based on teacher discussions and on input from students, in order to:

- address overtly Western-centric descriptions; for example, “addressing conflict directly” was required to score highly in one conflict resolution criteria, which might be perceived as favouring certain cultures’ approaches to conflict. This was changed to “Addresses conflict constructively, helping to manage/resolve it in a way that strengthens overall team cohesiveness and future effectiveness.”
- break broad criteria down into smaller sub-criteria; for example, “gives and receives honest feedback on others’ work” was separated into two separate criteria.
- add detail to some descriptions based on student feedback; for example “shows up to meetings on time” was changed to “shows up to meetings as per agreed upon expectations (e.g. on time, or as per some other agreement”).

The team-member assessment was used in two, separate meetings, at different points in the project, as a tool to promote constructive feedback within the group. Teachers collated the results each time (average score for each criteria) and made them available only to each individual student, and not the group. The students were clear that the results and discussion from these two meetings would not affect assessment, and that the criteria and conversation during the meeting would remain confidential. They were given time in both meetings to interpret the feedback they had received, and then freedom to discuss any issues and possible ways forward, including discussions about the group contract. In contrast to the first two assessments, a third team-member assessment was used to partially influence grading decisions in cases where students seemed to have put in significantly more, or less, work during the project. This was a condensed version with students only able to assess based on six main criteria areas; the sub-criteria descriptions in each main area remained visible, but students only responded to the overall, main criteria, in order to reduce student workload, and get general, overall impressions, rather than specific responses to each sub-criteria. The collated results of this assessment was not seen by students, and this was the only context within which the team-member assessments actually had the potential to influence assessment.

Other Activities

Two more in-class activities are of interest. In a final meeting, which started with some input on conflict management, students reflected on the Thomas-Kilmann conflict mode instrument (see, for example, Brown, 2012) by positioning themselves spatially in a room, to reflect upon which of the five approaches to conflict (avoiding, competing, compromising, accommodating, and collaborating) best reflects their approach during the project. This was used to prompt discussion of conflict resolution strategies, and how conflict had been handled in their groups. The second activity involved providing positive feedback to each group member, describing what was appreciated during the project, in order to shift focus towards positive affirmation in the final stages of the project.
RESULTS AND EVALUATION

The group diversity activities were evaluated in four ways: a short evaluation in the final session; a final course evaluation; optional reflection essays from the students; and interviews conducted once the course finished. 29 of 31 students completed the short evaluation and 14 completed the final course evaluation. 16 students completed reflection essays. Five students volunteered for the interviews, all of whom were international students. Using primarily the reflection essays, themes were identified from the student comments which were then coded by the authors.

Student Evaluation Results

The results of the short evaluation were very positive, especially for the workshops. 68.9% of the students felt that the first workshop was very useful or useful and this increased to 72.4% for the second workshop. Only two students felt that the first workshop was not useful and none for the second. The introduction seminar was not as highly ranked (57.2% felt it was very useful or useful) and three felt that it was not very useful, seeming to indicate that it is the occasions where the students are active which they appreciate the most. In the final course evaluation, students ranked the group diversity activities with an average of 4.21 out of 5. This went down to 3.21 when it came to the individual group assessment activities (see comments on this further down in “reflections on peer group assessment”).

Reflection and Interview Results

From the interviews and reflection essays, the following themes were identified: attitudes to diversity; reflections on the group contract; reflections on the peer group assessment; the importance of communication and attitudes and roles within the group.

Attitudes to Diversity

Students stated that they were positive to working in culturally diverse groups (cf Summers and Volet, 2008) and saw the reasons behind it. In many cases, they appreciated the range of experience that the group brought with them and the learning experience this provided: “Big diversity means a great variation in experience and knowledge, which has resulted in a fruitful project with very positive results. However, the road has not been straight and issues that I usually take for granted, has in the project been re-defined from my perspective”. (Swedish student)

In this case, the Swedish students on the course had had a lot of previous input and experience with group dynamics from their Bachelor program, but still needed extra support when it came to the culturally diverse groups. Another Swedish student commented: “Diversity can be really great if it is handled in a correct way, if not, it can be disastrous instead”.

Of course, diversity does not necessarily have to be in terms of cultural background. There can be also be diversity in terms of technical background, personality, motivation, amongst many other aspects. One issue that was seen as more challenging by some students than cultural differences were differences in the level of ambition of the students. One Asian student interviewed spoke of the frustration of aiming for high grades in group work because he was aiming for a scholarship, for example.
Reflections on the Group Contract

Many students commented that drafting the group contract was a useful process in terms of defining roles and dealing with conflict. One Swedish student commented that “creating a group contract in the initial project stage is an important and fruitful assignment”.

However, in the interviews, one Asian student commented that the group contract needs to be followed up on, since in his group, when there was conflict, they did not follow what was agreed in the contract.

Reflections on the Peer Group Assessment

Many students commented that this process was the most useful of the group diversity activities, particularly the use of the assessment for ongoing feedback on their group. One European student commented after the first team assessment that: “This was a very important milestone in the group and one of my biggest learning points of group dynamics. It became clear that some things were difficult to some of the group members”.

They appreciated the opportunity to meet as a group and reflect on the feedback they had received and that the feedback given in the assessment was anonymous, which facilitated honesty. In many cases, this generated discussion about participation in the group and how to create a positive group atmosphere, through, for example, social activities. Some individuals commented on the fact that they were aware they dominated discussions, while others realised they were too quiet. The process of grading each other meant that they took it seriously. In some cases, they could see improvement. In the interview, for example, one Indian student commented on the fact that his punctuality improved during the course. Through the feedback and group discussion, he realised that this was more of an issue in Sweden than in his home country and made an effect to work with that aspect.

However, the assessment was also described as a “coin that has two face”. Issues were that it was not always easy to set numerical values to some of the concepts, the timing of the assessment affected what was possible to grade, that it was difficult to compare from one assessment to the next because understanding of what the criteria meant changed; that there is the risk that groups postponed discussions of conflicts until the workshop; and that there were too many assessments.

The Importance of Communication

Communication was highlighted by many students as critical to a well-functioning group. Two key aspects were mentioned: the importance of openness in communication and being able to bring up issues in the group. The second aspect was the importance of using English. As regards the first point, in the interviews, one Asian student expressed it this way: “It’s important that people can express themselves freely with no repercussions. Also to create a platform for people to criticise freely”.

This is a process that takes time. This particular student gave the example of another student in the group who had confided in him some of his frustrations with the group work, but did not dare to bring these issues up with the group as a whole, which he found a challenging and sensitive situation.
In the second aspect, that of using English, an Asian student in the interviews commented on the varying levels of English from different nationalities and that this could become a hindrance when it comes to group discussions.

**Attitudes and Roles Within the Group**

Two aspects discussed in the reflective texts were the balance between work and socialising and the role that students took in the group. In terms of socializing, this was particularly appreciated by the international students. One Asian student commented: “The best part I believe is that we relax and have fun together. For example, having FIKA (Swedish word for coffee break) and going off topic for a short break TOGETHER” (student’s own capital letters, author’s comment on fika).

In the interviews, one Asian student described Swedish working style as working hard from 8-5 but not longer. In comparison, he felt that the international students were willing to stay longer. This can be related to the social situation, in general, where the Swedish students are at home and possibly have more commitments outside the study environment.

In terms of roles, students fell into two groups, those who saw themselves as leaders and those who did not. We encouraged the students to consider their roles in the first seminar in both the group contract and the SWOT analysis. Some found that they needed to compromise on their role when there was, for example, another leader in the group.

**CONCLUSION**

A number of studies have shown that, in order to have well-functioning, culturally diverse groups, those groups need support. Leask (2009) comments that:

“simply requiring home and international students to work together in groups on tasks, without adequate preparation or support, will not lead to meaningful and valued interaction between the two groups or support internationalisation of the curriculum.” (p.211)

This support can take place in a number of ways. This article has focused on activities that have been used for a number of years in group dynamics courses, for example, peer group assessment, group contracts, and SWOT analyses, and analysed their use in a culturally diverse project course.

Our key findings concern attitudes to diversity; communication; and students finding their own roles within the group. Cultural diversity means a greater variety of experience, knowledge and expectations, which can create affordances as well as frustrations. The challenge is to foster open communication, and mutual trust and respect between group members, which is the basis of a well-functioning group (Duhigg, 2016; Wheelan, 2014,). By creating a structure for this through a group contract and then continuous peer assessment, group members were given a forum to set expectations and express their feelings about the group anonymously.

However, this was by no means a perfect solution. Some student reflections still expressed frustration with uneven workloads and one interviewee reflected that students still tended to revert to their country groups when given the chance. Therefore, in order to achieve the goal of “fostering intercultural cooperation”, there needs to be constructive alignment such that
these issues are included as program and course goals; addressed throughout the program; and assessed accordingly.

Please note: Nationalities are given of students in the 2 major nationality groups of Sweden and India. Otherwise continents are given when there was only 1-2 of that nationality in the class to maintain anonymity

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BIOGRAPHICAL INFORMATION

Becky Bergman is a lecturer in technical communication at the Division for Language and Communication at Chalmers University of Technology. Her teaching at Chalmers involves communication courses for engineering students of all disciplines and levels, primarily electrical engineering and shipping programs at the undergraduate level and Master’s level communication and writing courses. She also conducts workshops for faculty on issues concerning teaching in English and intercultural communication. Particular research interests are intercultural communication, integrated language and content teaching (ICL) and peer reviewing.

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INTEGRATING SUSTAINABILITY AS A CRITICAL SKILL IN A CDIO “PRODUCT DEVELOPMENT” COURSE

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ABSTRACT

There is a pressing need to formulate and implement engineering solutions that guarantee both environmental and social sustainability in a world facing severe challenges identified in the global agenda through the Sustainable Development Goals (SDG). Consequently, sustainability is increasingly recognized as an essential outcome in engineering curricula all over the world. Despite recent efforts to include sustainability in the scope of engineering CDIO projects, there is a lack of a common framework to consider sustainability and specific methodologies to achieve the essential integration of strategic, social and environmental issues in this type of courses.

The INGENIA courses, based on the CDIO paradigm, taught in the first year of the master in industrial engineering at the Technical University of Madrid (UPM) are trying to consider systematically the different dimensions of sustainability to provide future engineers with the necessary skills to successfully incorporate sustainability in their work. This contribution presents a case study to illustrate and assess the methodology used to integrate sustainability as a critical skill in a product development CDIO course specifically. This methodology intends to incorporate environmental, social, ethical and other strategic factors related to the global sustainability of a product even before the design stage. Improvement potential from the sustainability point of view is considered as a key factor to define the prototype basic design and capabilities. Stakeholders and environmental opportunities are analysed along the market study and business plan. Later on, during the design stage environmental and social issues are included as design rules to identify optimal engineering solutions under a life cycle assessment (LCA) perspective.

The INGENIA “Product Development” course has been running for three years now. In this paper, we describe how the CDIO experiences have evolved and the corresponding assessment of sustainability skills of our students according to our experience. Further challenges and potential improvements are also discussed.
KEYWORDS


INTRODUCTION

It is widely recognized that the world faces serious challenges concerning sustainability. The international agenda to end poverty and protect the planet are is defined through the Sustainable Development Goals (SDG) (United Nations, 2016). Tackling this issues implies the involvement of governments, companies and civil society. Engineering also plays an important role in the achievement of these targets. In particular, engineering may help decoupling human well-being from resource depletion as well as social and environmental impacts. This is the reason why it is essential to drive engineering education beyond technical skills (Hernandez Bayo et al., 2014) and integrate sustainability in the development of processes, products and systems in general.

The Escuela Técnica Superior de Ingenieros Industriales of the Universidad Politécnica de Madrid (School of Industrial Engineering, Technical University of Madrid (ETSII-UPM hereafter), launched in 2014-15 the new Master’s Degree in Industrial Engineering which includes a series of INGENIA subjects (Lumbreras et al., 2015; Lumbreras et al., 2016) based on the teaching-learning CDIO standards, covering the majors included in the curriculum (Table 1).

Table 1. Available "INGENIA" courses in the 2016-2017 academic year

<table>
<thead>
<tr>
<th>Different INGENIA Subjects</th>
<th>Product / system developed &amp; objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automotive Engineering: Formula SAE</td>
<td>Students take part in the complete development project of a competition car, from the conceptual design, to the final competition.</td>
</tr>
<tr>
<td>Product development</td>
<td>Students live the whole process of creating an innovative machine, from the conceptual design stage, to the final trials with real prototypes, searching for design improvements.</td>
</tr>
<tr>
<td>Everyday life products / household goods</td>
<td>Students live the whole process of designing innovative products, from the concept step, to final simulations and trials with prototypes.</td>
</tr>
<tr>
<td>Systems engineering</td>
<td>Students experience the process of designing a smart system, using state-of-the-art engineering resources and taking account of the whole life-cycle. (A set of co-operative drones in current year).</td>
</tr>
<tr>
<td>Electronic devices: The School of the future - Smart ETSII</td>
<td>Students live the whole process of creating a new electronic product, oriented to improving everyday life in our ETSII-UPM, from the concept, to the prototyping stage and trials.</td>
</tr>
<tr>
<td>Industrial construction projects</td>
<td>Students experiment with information management and project planning resources applied to a real industrial construction project (a beer-factory in current academic year).</td>
</tr>
</tbody>
</table>
Electrical systems design | Students live the development project of an electricity supply network, from an initial renewable energy source to population.

Biomedical engineering design | Students experience the process of creating an innovative medical device, from the conceptual stage, to the final trials with prototypes.

Videogames design | Students conceive, design, implement and debug a software system, mainly videogames or emulators that are built taking into account the mathematical and physical basis of the problem being addressed.

Acoustic Engineering industrial applications | Students face the design and implementation of engineering solutions from the acoustic perspective in the scope of industrial, transport and environmental sectors.

Computer-aided Engineering | Students participate in the design of advanced, new materials with practical applications to social needs (shape-memory polymers and biomimetic and self-assembling materials) in a collaborative environment.

Motor-Gen: design and manufacturing of a thermal engine | Students design and build a thermal engine by reusing existing materials and artefacts working in multi-disciplinary teams.

These subjects are 12 European Credit Transfer System (ECTS) equivalent, structured in three modules:

- **Module A (Technical):** 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.
- **Module B (Transversal skills):** 15 hours for workshops to improve skills and techniques on teamwork, communication, and creativity.
- **Module C (Sustainability):** 15h for lectures and workshops about environmental and social impacts, ethics, and, professional responsibility.

Module C of INGENIA courses are intended to include a series of items of the CDIO Syllabus 2.0 directly related to sustainability (Miñano et al., 2016). However, there are few references regarding effective teaching and learning strategies that holistically and systemically address the integration of sustainability in CDIO courses (Brodeur, 2013). Despite the development of a general conceptual framework for the integration of these outcomes within INGENIA courses, briefly described in the following section, there is a clear need for further work to guarantee that fundamental sustainability principles are intimately integrated in each of the INGENIA courses, taking into account their particularities and specific teaching methodologies. This contribution reports on the activities done and main prospects to achieve this target within the “Product Development” course.

**GENERAL FRAMEWORK FOR THE INTEGRATION OF SUSTAINABILITY INTO CDIO COURSES AT ETSII-UPM**

The methodology developed to systematically consider the different dimensions of sustainability, including ethical and strategic aspects in CDIO courses at ETSII-UPM is presented in Miñano et al. (2016). It is based on a practical approach that enables to consider sustainability and ethical issues by a systematic exploration of all lifecycle phases. Besides providing a holistic view needed to avoid negative impacts (Cheah, 2014), it allows...
the identification of new functionalities and options to improve the product being developed. This methodology tries to assess the three classic dimensions of sustainability (economic, environmental and social), emphasizing that all of them have to be deeply grounded on the ethical and professional responsibility. Honesty and ethical compromise is identified by the employers or our graduates as the most valuable outcome (Fundación everis, 2016). From the academic perspective, reflecting on the ethical and professional responsibility dimensions of their work helps the students understanding the importance of social and environmental impacts of the products they develop. A fourth strategic dimension intends to integrate all economic, environmental and social considerations under a unified long-term, shared-value creation perspective. These aspects cannot be studied separately, that’s why the methodology proposed also includes the relationships with the different stakeholders that may be affected by the technology/service/artefact developed in the project (Figure 1).

![Diagram showing the integration of sustainability and ethics in the INGENIA subjects](image)

**Figure 1. Framework for integrating sustainability and ethics in the INGENIA subjects**  
(Miñano et al., 2016)

Early in the CDIO course, the students are asked to perform a first screening of the possible ethical, social and environmental issues related to their project in the context of a previous analysis of the technological sector the project is framed in and its organizational specificities. In the second phase, students have to select the most relevant issues to their project from the ones identified in the previous step, and analyze them in depth while working in design and implementation of their project. Different methodologies are proposed for environmental and social analysis. The environmental analysis is loosely based on the Life Cycle Assessment (LCA) methodology, generally recognized as a useful approach to integrate sustainability into CDIO-based engineering courses (Jeswiet et al., 2005). In the case of social impact, a selection of the most relevant impacts is discussed and agreed so the students can think of the consequences of each of them and analyze their capacity to influence them. To make the process more effective, the working teams are asked to identify relevant stakeholders, regulations, laws, ethical codes related, etc. and pondering on the possibilities of an assessment or quantitative evaluation of the impact.

The third phase within module C aims at quantifying and measuring the impacts selected in the previous phase. When possible, the students will test the product, studying the interactions with potential users or affected groups, so as to contrast the expected impacts or
to identify new ones. Although this is highly variable depending on the project nature and it is not always possible the students are asked to produce a final report where they have to reflect on this impacts and justify how the design of their product/service incorporates the constrains and opportunities related sustainability issues.

While this general approach has been found useful to integrate sustainability issues in CDIO courses, the wide range of activities covered by INGENIA courses (Table 1) and the particularities related to specific teaching-learning approaches and specific course planning make it necessary to perform a more detailed analysis on how module C can be integrated more effectively in every specific course, such as the one on product development discussed in this contribution.

PRODUCT DEVELOPMENT COURSE

The Product Development course (Proyecto de máquinas) (Munoz-Guijosa et al., 2016) is one of the INGENIA courses offered by the Department of Mechanical Engineering at ETSII – UPM, a Department with extensive experience with CDIO courses (Díaz Lantada et al., 2013; Chacón Tanarro et al., 2015). Students must Conceive, Design, Implement and Operate a product selected by themselves, taking into account sustainability issues during the whole course. Students work in 8-10 people groups, working on separated projects/products (3 or 4) and playing different roles during the course. The main tasks carried out during the course are:

- Product proposals
- Patent study
- Market study
- Product planning
- Business plan and risk analysis
- Pricing
- Concept design
- Basic and detailed engineering
- Computer Aided Engineering (CAE) and simulation: finite element methods (FEM)
- International sourcing
- Prototype manufacturing/testing
- Environmental and social analysis
- Redesign and documentation
- Reporting and presentations

The course also pursues the objective of making the students discover how technical knowledge and competences in acquisition during their studies can be applied in a project with real life constraints. They are free to choose the product in which they will be working the whole year. The only requirement is that it has to be an innovative electromechanical product which can be patented. 7 professors are available within module A to help and guide students during the project. Short lessons are taught every two/three weeks about the basics of every project stage and the tools to apply this theory to their product. They also have to deal with suppliers, fund providers, deadlines, complex equipment and processes and many other challenges that are usually present in real engineering projects. Figure 2 shows the course schedule, which already includes sustainability classes, which will be discussed later on in this article. This INGENIA is intended as a complete course that tries to empower the
students and give them the opportunity to fully develop their own ideas using all the resources available in the university. As an example, Figure 3 shows the product “Flabellum”, an automatic sunshade that automatically moves during the day in order to counteract the sun’s movement so the shade keeps in the same position. Students worked very hard and finally achieved the objective: to have a 100% working prototype at the deadline established. They learned how to design thinking on the whole product lifecycle, including its impact on society and environment. They also learned to use rapid prototyping equipment, designed and programmed the electronics, and also learnt welding, cutting, sanding and many other workshop jobs that were needed to manufacture it.

![Diagram showing course schedule]

**Figure 2.** Product Development course schedule
Figure 3. Different stages of the product development: concept design, CAE assembly check, FEM structural and thermal analysis, electronics software and hardware development, product testing.

In particular, sustainability issues are considered during the whole development process in the following aspects:

- During the product planning phase, not only economic considerations, regarding the objective cost and development deadline to guarantee the profitability of the project but also sustainability issues are taken into account. The selection of the functionalities the product must incorporate social and environmental considerations, in order to fulfill, for instance, work safety and ergonomics regulations, emission standards or ethical conflicts –worker reduction due to automatization, sourcing at underdeveloped countries, etc-. Social groups impacted by the product introduction must also be determined, and a particular study about one of them must be carried out (see implementation section).

- During the concept design phase, considerations regarding product performance and consequently energy efficiency are an important evaluation criteria in order to make decisions about the working principles which will be further developed. In the manufacturing process design, criteria as minimizing warehouse stock or internal movements, as well as waste products handling and minimization, are also discussed.

- During the basic and detailed engineering stage, students take into account, for instance, the existing regulations regarding forbidden materials. They must also select, among the feasible materials, the ones with smallest energy content and minimum environmental impact along their life cycle. They must also introduce design decisions regarding recyclability, as not mixing materials which will suffer different recycling processes, or selecting solutions for connecting parts which allow for an easy disassembly in the case
the connected parts must be separated for recycling. A report regarding the lifecycle environmental profile must be carried out (further details are given in the following section).

IMPLEMENTATION

The integration of sustainability into the “Product Development” INGENIA has evolved during the three editions of the course. The implementation described in this section correspond to the current approach based on the principles highlighted in previous sections and the experience from previous courses.

Course modules and planning

Activities within all INGENIA courses are arranged according to the 3-module structure briefly discussed in the introductory section. Although sustainability factors are considered throughout the entire project, 11 hours of specific sessions to discuss these issues (Module C) are included in the teaching planning of the Product Development Course. The 4 hours not allocated in the teaching plan (Figure 4) are used for tutoring classes outside the days specifically devoted to INGENIA (Mondays).

**Teaching-learning methodology**

Classes devoted to module C include lectures and workshops about environmental and social impacts, ethics and professional responsibility, as follows:

- The first class at the beginning of the course (S1 in Figure 4) consists of an opening lecture common to all the INGENIA courses’ students, before they even know the actual project they will be working throughout the year. The main challenges the Planet faces are presented and the fundamentals of sustainability briefly discussed. Then the basic 3-stage methodology (Mifano et al., 2016), expected outcomes and conceptual framework of module C (Figure 1) are introduced. The main concepts and tools relevant for environmental, social and ethical assessment are presented along with the reference

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**Figure 4. Complete subject class teaching planning including sustainability (module C) classes**
materials and tools. For a better understanding of social and environmental implications of Engineering practice as well as ethical and professional responsibility, students are asked to check the reference materials (reports, videos and other online resources) before the first sustainability session within their specific INGENIA. This session is deemed essential to raise students' awareness towards their responsibility and potential contributions to sustainability through their professional activity.

• Unlike other INGENIA courses, the products to be developed in the “Product Development” course are not defined beforehand. Despite providing the theoretical basis for product planning and problem solving, the first sessions within module A are used to discuss potential products to be developed during the course. The second sustainability session (S2 in Figure 4) is scheduled right after the products to be developed (3-4 every year) have been agreed through a voting procedure (Munoz-Guijosa et al., 2016). During this session (3 hours) the reference materials are discussed and a more specific lecture regarding sustainability is given in the mechanical engineering sector, highlighting important stages and potential relevant issues (e.g. energy and material fluxes throughout the product life cycle). It is particularly relevant to include a brief workshop regarding stakeholders during this first specific interaction with the students. This has been found determinant for the successful incorporation of social and environmental considerations and the selection of the functionalities the product must incorporate during the product planning phase. At the end of the session, the working groups are given their first assignment that consist of a first sustainability report (the basis for the final deliverable) that includes the analysis of stakeholders throughout the product lifecycle as well as the basic environmental life cycle assessment flowchart. Although at this stage the details regarding the different stages (resource extraction and processing, design, manufacturing, distribution, use, collection and recycling/disposal) are not known, this exercise is very interesting for them to gain a better understanding of the potential implication of their product from a wide perspective and thus, to include this kind of considerations into their designs.

• The next session (S3, 3 hours) is scheduled 1.5 months later, after the concept design is completed. Product working principles and manufacturing process are already defined and incorporate sustainability criteria identified in the first stage of module C. In this class all interim reports are given feedback and there is an open discussion on the deliverables since many points raised in the revision of the documents are relevant questions to more than one group, regardless of their product particularities. As students progress in their designs, sustainability criteria are reviewed and relevant social and environmental issues are clearly identified. The assignment for the following class includes the amendments of the sustainability report and the proposal of topics for detailed assessment within module C. There are no hard rules to address the third stage of assessment and each group decides the more convenient approach and justification to define the boundaries of a subsystem for detailed analysis and impact quantification, when possible.

• The groups are given 2.5 months to work on their sustainability report so they present a first complete draft version in S4 (2 hours) after completion of the basic engineering stage. Students are encouraged to arrange office hours between sessions S3 and S4. Nevertheless, feedback on the previous deliverable is given as well as orientation for the final report.

• After the detailed engineering stage is accomplished, a general assessment of the sustainability dimension of the project is done and options to polish the final draft of each group are discussed during session S5 (2 hours).

Teachers’ Activities
At least two professors are appointed to supervise the learning process and integration of module C in the Project Development Course. These two faculty members have different expertise areas and have a focus on either environmental or social/ethical dimension of the project. During the whole course, faculty members participate in the sustainability sessions previously described and are responsible for giving feedback on the deliverables sent by the students as well as offering office hours to clarify concepts and discuss strategical issues. According to our experience, a close cooperation and coordination with professors from module A is essential to convey a coherent message and to achieve satisfactory results.

**Students’ Activities**

All the assignments within module C are proposed as group activities (students are grouped in relatively big teams of 6-12 people each) although usually a group member is appointed as the responsible to make the necessary coordination and linkage with module C teachers. Group members may take responsibilities on specific tasks or research needs to put together the sustainability report but special emphasis is made to guarantee that all of them are perfectly aware of principles, as well as design and implementation decisions with implications on sustainability. The amount of work envisaged for module C is equivalent to 1.5 European Credit Transfer System (ECTS), so the workload expected for each students regarding specific sustainability activities ranges between 37.5 to 45 hours.

**Tools**

A specific section including materials and assessments of module C is available at the moodle of the INGENIA course. The main reference materials are:

- Teaching guide: responsible faculty members and logistics, aims, methodology (3-stage assessment), planning, resources, evaluation criteria and annexes: procedures and indicators for each of the methodological stages, structure and format of the sustainability report and checklists for the identification of social an environmental relevant issues.
- Sustainability fundamentals: document to provide the scope of sustainability with links to online resources and videos
- Slides of the opening lecture: introduction to sustainability, global challenges, rationale and scope of module C, details of the methodology and examples for qualitative and quantitative analysis and further references.

**Deliverables**

Key guidelines for dealing with this holistic integration were developed and made available to students. Inspired by the Value-Sensitive Design method and other experiences mentioned in the literature review, we established four phases to carry out the works: identification of possible impacts, analysis and selection of the relevant issues, the technical phase, and a final reflection covering all the dimensions of sustainability. This is reflected in the structure of the sustainability report that each group has to produce during the course. The work done in this area has to be synthesized in a very concise document where an account of the main relevant issues and stakeholders are given as well as qualitative and quantitative analysis regarding the social and environmental dimension of their products. The students are asked to conclude by providing a justified assessment on how sustainability criteria have been integrated into their prototypes and how they add value to the product developed as well as the overall coherence of the project with professional responsibility.
Evaluation

Evaluation is based on the final sustainability report that constitutes the common deliverable related to module C activities for all INGENIA courses. This report is evaluated by the module C instructors and it represents 12.5% of the final score of the INGENIA course. Total score is computed from two separate scores assigned to the ethical & social issues and environmental assessments within the sustainability report. The evaluation is based on a rubric included in the teaching guide that was designed taking into account the expected global outcomes of the Master Degree. The rubric includes indicators and minimum performance criteria regarding knowledge, application and integration of sustainability concepts.
RESULTS AND DISCUSSION

Some examples regarding the discussion on relevant social issues, environmental life cycle assessment flowchart and quantitative analysis, taken from the sustainability report are shown in Figure 5.

Figure 5. Excerpts from students' sustainability reports

The projects developed during the courses 2014-15 and 2015-16 were:

- Automatic bag dispenser for fruit and vegetables at supermarkets
- Electronic fishing reel
- Smart coin purse
The students are working on the following products:

- Flabellum umbrella (automatic sunshade)
- Automatic pill dispenser
- Bindboards for snowboard

The products the students are working on this year (2016-17) are:

- Automated drink mixer and dispenser
- Mechanically-aided shopping trolley bag
- Disinfector for electric toothbrushes

Module C scores have been found to improve substantially, from an average of 6.5 in the first course edition to 8.1 in the second one. The corresponding scores regarding the ethical & social and environmental assessments were 6.3 and 6.8 in the course 2014-15 and 8.2 and 8.0 in the course 2015-16. Beyond module C scores, results of the INGENIA courses from the two first years (those of the current one are not available yet) have been analyzed from four perspectives: conceptual, methodological, students’ satisfaction and sustainability skills. Qualitative information has been obtained from classes, focus groups with professors and final reports prepared by students. Quantitative data was gathered from pre- and post-questionnaires with closed and open questions provided to students.

The conceptual perspective is related to the theoretical dimensions of sustainability for the INGENIA “Product development” course. For the sustainability methodology is very important the identification of stakeholders and materiality regarding the sector where students are involved. The relevant issues that have emerge are shown in Table 2.

Table 2. Most relevant sustainability issues highlighted by “Product Development” students

<table>
<thead>
<tr>
<th>Device</th>
<th>Year</th>
<th>Ethical, social issues</th>
<th>Environmental issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supermarket bag dispenser</td>
<td>2014-15</td>
<td>Labor market implications, sustainability awareness</td>
<td>Plastic (PE-LD) savings; energy consumption during operation</td>
</tr>
<tr>
<td>Electronic fishing reel</td>
<td>2014-15</td>
<td>Labor market and regulation implications, boost of fishing demand</td>
<td>Ecotoxicity related to Li-ion batteries and after life waste management</td>
</tr>
<tr>
<td>Smart coin purse</td>
<td>2014-15</td>
<td>Help for the elder and disable people</td>
<td>Recyclability of raw materials, impact of electronic components and batteries</td>
</tr>
<tr>
<td>Automatic pill dispenser</td>
<td>2015-16</td>
<td>Design for social need integrating all stakeholders view</td>
<td>Product design with low environmental impact criteria: raw material recyclability. Energy consumption.</td>
</tr>
</tbody>
</table>

During these two years, we have been able to discover that, even with a common framework to integrate sustainability into INGENIA “Product development” course, differences of use among the designed devices, made the sustainability agenda quite different for each group. Although the methodology presented was flexible enough to be applied to any kind of project, we noted that the most challenging scenario relates to devices oriented as consumer goods, without any specific orientation to cover basic social or environmental needs. Methodological considerations to adapt the general INGENIA sustainability framework to the “Product development” course, try to solve the mentioned conceptual challenges. The links between sustainability framework and product development methodologies must be reinforced. The identification of stakeholder needs and definition of the LCA flowchart are key issues to build these links.

The results of the evaluation of questionnaires of students’ satisfaction show that the efforts to find a smooth way to introduce sustainability in the “Product Development” course has been perceived. Table 3 summarizes the main results and shows that the assessment of most of the items related to module C have a positive trend. Information from the questionnaires of the first edition were essential to improve our approach to sustainability within the course. In the last year further modifications were made to improve issues such as documentation, guidance and sustainability contents in moodle.

Table 3. Summary of students’ degree of satisfaction degree of satisfaction - from 0 (worst) to 5 (best)

<table>
<thead>
<tr>
<th>Assessment of module C-related items</th>
<th>2014-15</th>
<th>2015-16</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Product development” sustainability specific sessions</td>
<td>3.00</td>
<td>3.59</td>
</tr>
<tr>
<td>Sustainability professors</td>
<td>3.69</td>
<td>3.68</td>
</tr>
<tr>
<td>Inputs for sustainability from INGENIA professors</td>
<td>2.92</td>
<td>3.74</td>
</tr>
<tr>
<td>Sustainability contents in moodle</td>
<td>3.00</td>
<td>3.03</td>
</tr>
<tr>
<td>Sustainability methodology</td>
<td>3.38</td>
<td>3.91</td>
</tr>
<tr>
<td>Evaluation criteria through students works</td>
<td>3.42</td>
<td>3.62</td>
</tr>
<tr>
<td>Global</td>
<td>3.19</td>
<td>3.59</td>
</tr>
</tbody>
</table>

The final objective of the sustainability activities included in the CDIO course INGENIA is to teach sustainability skills to the students. The data available of the outcome evaluation are common for all the INGENIA courses, and there is not specific analysis for the “Product Development” course. From the data gathered for the 2014-15 course (Miñano et al. 2016), can be pointed out that INGENIA courses made students more aware of ethical and social impacts, compared with the initial perception of only environmental ones as relevant. Particularly students improve the self-perceived ability to analyze social impact and the capacity to enhance the positive impacts of an engineering project. Although students have stronger fundamentals regarding environmental issues since they have a common specific course during their previous degree (Borge et al., 2011), INGENIA also helped them to gain a better understanding of environmental implications under a wider, life cycle perspective.
CONCLUSIONS AND LESSONS LEARNED

A methodology to include environmental, social and ethical impacts was developed and successfully implemented to the "Product Development" course. This methodology is derived from the common framework defined to incorporate sustainability into INGENIA CDIO courses but it is specifically integrated with the teaching planning and methodological approach (product planning, concept design phase as well as basic and detailed engineering stages) of the course. We found that the identification of stakeholder needs and definition of the LCA flowchart are key issues for a successful integration of sustainability in the conception and implementation of any product.

Both, final scores and students questionnaires point out that this methodology is useful to integrate sustainability in this course, although there is a need for specific adaptations to tailor the methodology for each product. In the future this methodology may be further refined and improved by analyzing stakeholders and materiality related to each specific project so more systematic and meaningful indications and orientation can be provided depending on the type of product being developed. The integration of sustainability has focused so far on the Conceive and Design stages of the course, since as stated before, this is the key for a sustainable product. Nonetheless, options to incorporate social, ethical and environmental criteria into the Implement and Operate stages should be also addressed in the future for a more holistic approach to sustainability within the course.

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DESIGNING PROCESS ENABLERS TO STRENGTHEN PROFESSIONAL SKILLS IN PROJECT WORK 2.0

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ABSTRACT

This paper aims to complement a previous paper by two of the authors (Flarup & Wivel, 2013) about how to design process enablers to strengthen project work. This article contains examples from eight first semester student teams (fall 2016 survey) and the staff surrounding these teams. The purpose is to illustrate how a few simple tools are able to strengthen the students, their professional mastery of teamwork and their general sense of well-being. What we also recognized – as a surprising finding – is that this feeling of general well-being seems to dramatically prevent the first semester students from dropping out of their studies and caused a higher student retention rate in the first and the second semester, which in general are critical periods for the students’ socialization. The article adopts the theory of self-efficacy and well-being (Bandura), and the conclusion is that mechanical engineering students feel much better professionally and socially in their project work when they have been trained in the program of general well-being. The article is related to the CDIO standards 2, 3, 4, 6, 7, 9, and 11 concerning personal and interpersonal competencies and social learning.

KEYWORDS

Well-being, self-efficacy, project work, process enablers, personality test, coaching, dropout, retention, mechanical engineering, personal and interpersonal competencies, standards: 2, 3, 4, 6, 7, 9, 11.

INTRODUCTION

The phrase "personal and interpersonal skills" is mentioned in six out of twelve standards in the CDIO Syllabus, and in a seventh standard, the phrase “social learning” is mentioned. This indicates that, not only in Denmark, but worldwide, there is a call for engineers with
sophisticated personal and interpersonal competencies combined with a high level of professional engineering qualifications; competencies and qualifications that contribute to the process required for project work and teamwork to be successful.

At the Aarhus School of Engineering, we are dedicated to training students in engineering skills in order to provide future employers with a professional, highly skilled engineering workforce. Joining the CDIO Initiative in 2010 resulted in the development of training activities in January 2012 designed to advance our mechanical engineering students’ personal competencies. We experience a growing demand for engineers that can work – with a quotation from Professor Edward Crawley – as “whole, mature, and sensible individuals” (Crawley, 2001).

As we have demonstrated in our first paper concerning this issue (Flarup & Wivel, 2013), the students feel good about these personal and interpersonal training programs, but we cannot assess it by simply looking at the grades (or rather, we have not tried). However, what we have found is, surprisingly, that the well-being of the students both positively affects their experience of the project work and their fellow team members and has had a positive influence on the general retention rate in the first and the second semester; semesters that are critical for the students’ decision to drop out or continue their studies. From January 2010 to August 2012, the number of dropouts (first semester) was reduced from 25% to 10.5%. One of the associate professors (first semester coordinator) has said: “Something works - but we don’t know why”.

The intention of this paper is to elicit the following issue: How can the well-being of the students in their project work strengthen their professional engineering skills and at the same time cause retention especially at the first and the second semester. Through quotations from the students, we demonstrate that the well-being implies a higher level of professional skills in doing project work and, as a positive side effect, a higher student retention rate.

Well-being

The concept of well-being is based on the social cognitive psychological behavior theory of self-efficacy (Bandura, 1994). Self-efficacy is the feeling of mastery. There are four sources for developing personal self-efficacy: 1) Mastery and self-efficacy in general – feeling that you are able to master your life and a challenge, 2) the influence from a role model – teacher or someone you feel alike and admire, 3) influence from social persuasions, meaning that the role model or other sources convince you that you are able to master a situation, and 4) how you handle your positive and negative emotions about yourself and the situation. Negative emotions are telling you that you are a failure, whereas positive emotions make you believe in yourself in every respect. The more you master your life in general, the more you believe positively in yourself, the higher level of well-being you feel. Role models convince you to do your best i.e. by coaching or other tools of persuasion. Research (DeWitz et al., 2009) has shown that university students with a high level of general efficacy and positive emotions about them selves and a high well-being have a lower risk of dropping out – even though they might meet overwhelming challenges - because their feeling of general self-efficacy is linked to a greater sense of purpose in life; whereas students with a lower general self-efficacy but a high sense of social efficacy and/or a high sense of academic efficacy surprisingly have a higher risk of dropping out even though they are doing well in a social context or receive high grades because they miss an overall purpose in life. The conclusion is that we have to train our students in developing a general self-efficacy, positive thinking, purpose in life, and well-being to make them “whole and sensible” (Crawley’s quote) and
better engineers and to prevent them from quitting their studies, which is a shattering, personal defeat.

When writing our first paper in 2013 about process enablers for strengthening project work, we were unaware that our question about how to assess these efforts by grades was unimportant. What we didn’t realize then was that good grades don’t lead to a strong personality and they don’t necessarily make you a better engineer. In our daily life we meet students for whom it is very stimulating to do these personal and interpersonal activities, and who enthusiastic adopt the skills in their professional life. We also experience students who on the contrary focus on engineering skills and find personal development boring and not relevant to their careers. Despite their different attitudes to these personal activities, 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. Since then, we have worked intensively to organize a program which motivates all kinds of students despite their attitudes to personal development to participate more comprehensively. In this context, we base our insights on theories of inner motivation, meaning that you have to feel autonomy, self-determination, positivity about the task you are doing and relatedness to other people, e.g. in teamwork situations (Deci & Ryan, 2000). As we wrote in the first article, the important thing here is that: “Personal and interpersonal skills are a tacit knowledge, learned and performed by the student through social and professional relations” (Flarup & Wivel, 2013, p. 1). In the following, we will explore this more thoroughly.

**The Program**

The table below outlines different elements of the interpersonal program. Each of the semesters of the mechanical engineering study program is different in terms of course program activities.

Table 1. Personal and Interpersonal Competencies course program

<p>| 1st semester | Psychometric test: Insights Discovery (a random choice, see <a href="http://www.insights.com">www.insights.com</a>). | Team coaching. The personality test is used in team coaching. Introduction to project management tools (e.g. Gantt Chart, Scrum Board). Communication tools are, e.g: • Talking stick (if you have the stick, you talk, if you do not, you listen) • Collaboration contract (see appendix) • Team poster • Team Effectiveness Wheel (see appendix) | Teaching in class (two lessons): Introduction to personality test + communication and perception | Process report: Two pages per person included in the project report. See keywords in appendix. |</p>
<table>
<thead>
<tr>
<th>Semester</th>
<th>Reuse of personal profile test.</th>
<th>Team coaching.</th>
<th>Teaching in class (two lessons): No report.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd</td>
<td>Reuse of personal profile test.</td>
<td>No team coaching. If there are any problems in the team, it is possible to contact the team coach.</td>
<td>Teaching in class (two lessons): Conflict management, team theory, social intelligence, including the personality test.</td>
</tr>
<tr>
<td>4th</td>
<td>Reuse of personal profile test.</td>
<td>No team coaching. If any problems arise in the team, it is possible to contact the team coach for a conversation.</td>
<td>Teaching in class (two lessons): Organizational theory and professional behavior, including reuse of the original personality test.</td>
</tr>
<tr>
<td>6th</td>
<td>Reuse of personal profile test.</td>
<td>No team coaching. If any problems arise in the team, it is possible to contact the team coach for a conversation.</td>
<td>Teaching in class (two lessons): Career planning based on the personality test.</td>
</tr>
</tbody>
</table>

As is evident from the table, the program consists of a mixture of teaching in different non-engineering subjects and the completion of a personal profile test forming the basis of team coaching and further teaching, which all in all is in accordance with the influential factors of the self-efficacy theory: mastery, role model, social persuasion, and positive emotions. Since the program was introduced in January 2012, ten semesters ago, we have witnessed a growing sense of well-being, a much stronger ability to work in teams, significantly increased tolerance and acceptance of each other, and an increased insight into personal and interpersonal competencies among the student population.

**SELF-EFFICACY IN PRACTICE AT THE MECHANICAL ENGINEERING STUDY PROGRAM**

As stated above, we will substantiate our findings by means of examples from the students’ process reports (fall of 2016) and statements from the staff. The examples are organized according to the self-efficacy theory, upon which our work is based, as its applicability has proven very robust.
Examples

The examples are based on quotations from interviews and process reports.

Purpose of Team Coaching, Personal Profile, and Process Report

Some students are very negative before they take the personality profile test and enter the team coaching room. They think it is a waste of time and, as a student writes in the process report:

“Humanistic nonsense? Maybe, but nevertheless, we were all a bit surprised at how much actually fit.”

“When I heard that we were to take a personality test that would divide us into different colors that symbolize our personalities, I thought, ‘what is this pedagogical bullshit!’”

“[…] Then when we got our Insights profile back, I was extremely surprised at how well it fit my personality. I could see myself completely in the description of my strengths and weaknesses. And when I read other people’s Insights profiles, it struck me how different we really are.”

“[…] I thought about it for a while, and it was not until we had our group meeting with [team coach] that it dawned on me, and I understood how each team member worked and expressed opinions differently. It was really an eye-opener for me; it was as if many things just fell into place, my view of other people changed. I do not claim that I understand all people now, but it gave me a greater appreciation as well as food for thought.”

As they work with the process report, the team members reflect on their own personal and professional development as well as the team’s development. One team writes in its report:

“The Process Report is a tool. It is a way to gain knowledge and an ideal opportunity to reflect on the project. A product development phase is always a new journey, and you will constantly bump into unexpected problems, personal conflicts, and time constraints. But how does the team tackle these problems? To what extent does the team manage to make room for the group members' strengths and weaknesses? That is exactly where a project like this strengthens and develops all its participants; you learn to be aware of your colleagues, you learn to help each other, and together, you gain detailed insights into how you, as a group, are able to develop and create a product that the world has not seen before.”

In the team coaching sessions, we work with the four above-mentioned parameters: Self-efficacy, role model, social and verbal persuasion, and mastery of positive and negative emotions.

Self-Efficacy

“I feel that this project workshop has given me a better understanding of the techniques that make up excellent teamwork. I’ve learned many tools and gained a lot of knowledge about not only my way of working/expressing myself but also other team members’ way of responding. So, I’ve learned to react and communicate differently with my fellow team members, depending on their individual profiles and personality traits.”
“We believe that we all, to varying degrees, have gone through a personal development in course of the project, and we have challenged ourselves in areas that are not necessarily our strongest fields of competence. We’ve been good at providing scope for each other’s personal development and for working on the goals we each had set for ourselves. Also, we structured the project work so that we worked with tasks that accommodated our strengths and weaknesses. In particular, the various roles in the team served as a development tool for the weak points, whereas in the different sub-projects, we worked with our fields of competence. [...] We are convinced that we leave this project and enter into the next with the knowledge that we have grown, both on a personal level and as a group. We have gotten to know ourselves and each other better by taking on unfamiliar roles, while giving each other the space to work in the way that best suited the individual team member.”

“We realize now that we, as a team consisting of a bunch of diverse individuals – both privately and professionally – can work amazingly well. Sometimes you get stuck in your attempt to solve a task, we even ended up a couple of times in situations where the whole group sat in silence, and nobody got anything done. And not until after a little while did you realize that your teammates were in the same situation as you. We realized that the best way to proceed was to review the status of the project and discuss what still needed to be done. Summaries and status meetings. Often it could provide some inspiration to hear what the others in the group had been working on.”

“We have developed as a team in this process; initially, we didn’t even know each other’s names, now we continuously strengthen our cooperation and social relations, although our personal profiles do not necessarily match. Even if we sometimes are very different in terms of how we work and what our particular focus is as far as the project is concerned, we have managed to find a balance, making everyone in the group feel safe and cooperate energetically on the chosen project.”

**Role Model**

The team coach plays a vital role in the program, as it is exceedingly important that the students can identify with and trust the person. At ASE, the first semester team coach is a female mechanical engineer. She says about her role:

“They meet me both as a teacher and as a team coach. I am therefore able to draw on my education as a mechanical engineer as well as my experience as a development engineer and as a teacher. I also tell them that I am the internship coordinator, which means that I will meet them again later on in their studies in connection with their engineering internship as well as a supervisor and teacher. They appreciate when I tell them that team work is important for an engineer. I am able to convey to them the importance of working in a team. The fact that I am an engineer and that I consider my students to be my future professional colleagues entail that I am able to approach them on an equal footing; or as equal as it can be considering that I am their teacher and at their parents’ age.”

“At the team coach meeting itself, we of course started out by going over the roles, the cooperation agreement and our headlines. Afterwards, we started talking about things, asking the coach and each other questions, which turned out to be really productive. The conversation, moderated by the coach, especially revolved around our Insights profiles. That meant that we were guided into addressing a lot of issues that might have seemed pathetic to address outside the meeting. Consequently, the team coaching session meant that we got to know each other better, but it primarily meant that we got to know ourselves. It gave us
some great ideas for how to have a fruitful working relationship and friendship moving forward.”

Social and Verbal Persuasion

One of the team coach’s tools is to persuade the student to develop new skills using arguments from the profile test. A student writes in the process report:

“During the meeting with [team coach], she said that the test showed that I was in an area that also defines a leader. And that is something that I would like to explore further to see if I can find the inner leader in me. Other than that, I have been working on opening up; for instance, I visited Rema 1000 [a Danish supermarket] and interviewed one of the employees.”

Another tool is the Team Effectiveness Wheel (see appendix), which functions as key words for what works in the team and what does not (an issue for the coaching session). One of the teams states in the report:

“Preparatory to the team coaching session, we appointed a process manager and a project manager; we really didn’t put that much thought into our choice, as we figured that we would take turns, allowing everybody the chance to take on the roles. Then we defined the roles together. Shortly before our team coaching session, we prepared three headlines (key words) that the team was good at along with three headlines that we would like to be coached on.”

Another student writes about being challenged socially and verbally by the teammates:

“I am well aware that I can be inflexible. I am not confident about simply taking the plunge without thinking things through beforehand. That is why it is important that we have people in the team that are of the opposite type; people who are able to take me out of my comfort zone once in a while.”

Positive Emotions

When looking at the students’ ability to handle negative and positive emotions (a resilient attitude to challenges and personal weaknesses gives a higher feeling of efficacy no matter what), we ask them to study the paragraphs in their personal profiles about strengths, weaknesses, and blind spots and to share this with the team. The following is a process report quotation from a student:

“My strengths are to encourage structure and order, maintain established rules and procedures, and I am stable and reliable. My weaknesses are that I lack confidence in my own judgement, even though I am most often right. I can be stubborn when I’m under pressure, and I sometimes avoid solutions that entail high risk. My contribution to the team is that I will follow the project through, that I support the team devotedly, and that I am able to focus on both task- and person-related subjects where the team is involved.”

Another student writes about how to handle feelings of not being not heard in a communication:

“[...] as I had failed to use the suggestions for communicating with my opposite [personality-wise]. I forgot to make use of my advantages and think things through before commenting,
which triggered my opposite who has a problem with vague and inexact communication. I was out of my depth and wasn’t able to think my arguments through, as I was pressured for an answer. This made me weak, and all of a sudden, I lost track of my logical viewpoints, which meant that I somehow just had to give in and let my opposite ‘win’.”

Finally, the personality profile test tool and the process report provide the students with the opportunity to reflect on their way of handling feelings, aggressions, and positive and negative emotions. One student indicates:

“I don’t respond positively to viewpoints that are different from my own, which produces premature conclusions because I lack the benefits that might spring from having a second opinion. My capacity thus lies in gathering people to negotiate a solution, if this is necessary for the project. Other people’s mistakes make me angry. Neither do I appreciate critical comments about my personal qualities, and I interpret these as an attack on my personal integrity. I am an extreme realist and rely heavily on my common sense.”

SUMMARY AND CONCLUDING REMARKS

As the quotations above demonstrate, the personality profile test tool, the team coaching sessions, including project management tools and communication tools, and the process report all indicate a very high level of self-reflection on part of the students as to their personal and professional development. This corresponds with the self-efficacy theory, which defines well-being as a feeling of mastering the situation professionally and personally. The theory shows that a guiding process by a role model aiming to strengthen efficacy is necessary for students with a more or less positive view of their own skills. This is exactly the purpose of the team coaching sessions headed by an engineer taking on the role as coach. Albert Bandura, the father of the theory of self-efficacy, points out that the levels of feeling mastery and personal positive emotions are of crucial importance for enduring challenges, and that those two, mastery and positive emotions, are more important than role models and verbal persuasion, which are just means to acquire these competencies.

The Head of the Mechanical Engineering study program observes a new engineering culture at ASE, which is aimed at in the CDIO standards as well. 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’s 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.”

She continues:

“Retention of students by means of personal and professional competencies is very difficult to define seen in relationship to the whole course of study. In general, we see a dramatically low dropout rate during the first two semesters as well as a lower dropout rate at the later semesters compared with before we introduced these activities. We think that we have eliminated the unqualified dropout in the initial phase of the study by training young people to cope with fear and negative feelings and to behave much more capable and mature towards studying at an engineering university.”
Summarizing on the aspect of retention, the dropout rate of the mechanical engineering study program has been dramatically reduced at the first two semesters as a consequence of the program to enhance the students’ personal and interpersonal competencies, as described in the CDIO syllabus. In the succeeding semesters, the dropout rate is also lower than it was before 2012. The students deciding to embark on another professional career or failing to pass their exams are typical reasons for dropping out on the second or third year of the study. This kind of dropout is a much more qualified decision for the individual, although dropping out is still a personal defeat.

The team coach concludes:

“We believe that the students’ high level of self-efficacy and the fact that they work with their understanding of themselves and their teammates result in a lower dropout rate in general. We see retention in close relationship with an insight into personal and interpersonal competencies. We haven’t investigated whether other activities have had any influence on the retention rate, but we haven’t changed the study program or the curriculum during this period, so we have reasons to believe that the personality test tool, team coaching, and the focus on collaboration in the teams are of major importance for the students’ wellbeing and retention and that a role model is a safe backup for each student. All the teachers have taken this personality test, and they know about the rationale of the test. This creates a common, cultural framework for both students and staff that also has an effect on the students’ general capacity to engage more actively in the teaching and in the learning processes.”

One of the teams has reflected on what would be worth bringing into the next semester (into new teams). They write in the process report:

“What we would bring:

- Planning tools: morning meetings, logbook, after-work meetings, calendar, daily schedules, process poster.
- Division into manageable intermediate aims.
- Putting as much energy in the process as in the product.
- Calm and professional conflict resolution.
- Changing roles in the team.
- Talking stick.
- Use of Google Drive to ensure that everybody is involved in everything.
- Early decision on fixed structure.

Good advice for next year’s students:

1. It is worthwhile to use time and energy on considered planning.
2. Maintain focus on the users and the process.
3. Start working on the report early on in the process.”

What we see above is a new culture at the Mechanical Engineering study program at ASE. It has been a great success, as the tools have been disseminated to the whole Engineering School. What we see is that the students proactively contact the team coach if they expect challenges in their team work. They know where to get help and they know the tools. One of the seventh semester teams writes (in an email to the team coach):
“As it is right now, only two thirds of the team is aware of the issue. It is not a problem as such, merely something that should be addressed in order to make sure that it doesn’t become one. I am planning on bringing it up, and in that connection, I would like to explore the options available. So, what I would like for now is a quick talk with you in order to find out if it falls under your area of expertise.”

FURTHER WORK

We intend to continue to work with these personal and interpersonal tools together with the professional training of our engineering students. What we see is that the industry asks for these qualifications and competences. Therefore, in order to further support our findings to date, we plan on introducing a test of the students’ individual character strengths and virtues in order to stimulate self-control and grit. This is based on Martin Seligman’s research (Seligman, 2004, 2011) on why and how some people endure and keep on track – and others do not. This is intended to stimulate the engineering students’ feeling of an overall general purpose of life, which is as demonstrated above a significant factor for keeping students from dropping out of their studies (Koch, 2013).

REFERENCES


BIOGRAPHICAL INFORMATION

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APPENDIX

Team Effectiveness Wheel

As a part of the preparation prior to the team coaching session, the team is asked to prepare:

- Three key words for what works in the team collaboration processes.
- Three key words for what the team finds challenging and would like to be coached on.

The Team Effectiveness Wheel is a tool that corresponds to the Insights Discovery personality profile.


Process Report

The content of the process report is structured according to the following headlines. This report is an addition to the project report and forms part of the overall grade for the project.

1) Introduction and purpose of the report as the team sees it.

2) The personal development in the team – for the individual student and for the team.

3) The professional development – management of the project.

4) Learning – which topics and aspects, tools and themes will the team bring to next semester’s team work? The team must gather the experiences from the lectures, the process report, and the project report and take a position on the following:

- Which good experiences in terms of the processes and the tools will the team bring to the second semester and continue to develop (the second semester teams will – as one of the first things – be asked to evaluate on the basis of their experiences from the first semester) in accordance with the phrase: WHAT SHOULD WE DO MORE OF?
- Which less than good experiences will the team refrain from bringing to the second semester in accordance with the phrase: WHAT SHOULD WE DO LESS OF?
- Which three good experiences and which three less than good experiences will the team pass on to a future first semester team?
INTEGRATING SUSTAINABILITY ASPECTS IN MINING ENGINEERING EDUCATION

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ABSTRACT

Providing higher education in the field of Mining Engineering means having the responsibility to provide the necessary competences for the next generations of decision makers in the field of raw material supply. These competences are the basis for solving future problems. A significant issue in the future of mining is Sustainable Development. It comprises the main future challenges in the conflict area between economics, environmental and social matters. The alumni of our study program should be aware of these and prepared for upcoming tasks. Therefore, a continuous integration of Sustainable Development aspects into the curriculum of the international Master of Science Program Mining Engineering at Clausthal University of Technology has been undertaken.

The objective is to prepare graduates at best for their future as professionals in Mining. For the integration of Sustainability two approaches were followed simultaneously. On the one hand, aspects of Sustainable Development were integrated in the usual technical oriented lectures. On the other hand, a compulsory lecture was installed to give the opportunity to develop an own view of Sustainable Development in Mining.

The lecture titled Advanced Underground Mining combines project-based learning with the approach of just-in-time teaching. The objectives are to link the existent knowledge from other lectures, in order that the student can act as an expert and communicate adequately with different stakeholders. The objective of the lecture titled Sustainability in Underground Mining is to encourage students to develop and express their own opinion. To this end, students elaborate first together in an active atmosphere the Basics and Methods of Sustainable Development, using fictional and real life examples and discuss them. In the second part, different stakeholders give presentation on their field of action. The students get the opportunity to discuss their action and approaches with regard to Sustainability.

The paper presents the mentioned lectures as non-traditional teaching and learning activities. It focuses on frame condition, learning objectives, realization and results.

KEYWORDS

Sustainability, Mining Engineering Education, Lecture Design, Innovative Teaching and Learning, Standard: 2, 3, 7, 8, 11
INTRODUCTION

Mining is the backbone of economy. The supply with mineral raw materials is directed to their extraction in underground and surface mines. It provides welfare and growth of economy and society. An average American born in 2016 will need more than 1.417 tons of minerals, metals and fuels in their life. (Minerals Education Coalition, 2016). Taking this as a basis and considering the increasing world population and prosperity level, it can be concluded that the demand for raw materials will increase in the future as well.

Meanwhile, the complexity of mineral deposits, the demand of raw materials and the increase in knowledge are leading to new economically, environmental and societal challenges. The combination of these issues leads to the main future challenge: Performance of Sustainable Mining. Future Mining Engineers act in the conflict area between the requirements from economy, environment and society. Hence, the consideration of Sustainability in their education represents an opportunity as well as responsibility for the future, which are taken by implementing the aspect of Sustainable Development in the master’s course Mining Engineering.

OBJECTIVE

The objective is to design higher education in Mining Engineering that meets the needs, tasks and working reality of future Mining Engineers in their work life by implementing aspects of Sustainable Development in their study program. Therefore, it is essential to identify correct learning objectives and design a concept which aligns them with the teaching and learning activities as well as the assessment.

METHODOLOGY

To find a correct design for the implementation, already existing approaches were investigated. Appropriate aspects were used and supplemented by already-existing ideas and thoughts for getting a consistent and suitable implementation approach for the higher education of Mining Engineers at Clausthal University of Technology.

COMMON WAYS OF IMPLEMENTATION

In order to find a way of implementation, research was undertaken to find, on the one hand, important aspects to consider in the design and, on the other hand, to revise already implemented approaches.

The United Nations Educational, Scientific and Cultural Organization (UNESCO) declared the time from 2005 to 2014 to be the Decade of Education for Sustainable Development (ESD). Although the topic of Sustainability is diverse, essential characteristics were defined in many forms. (UNESCO, 2005) These can also be found in important aspects (Timpson, 2006) mentioned for successful education in Sustainability:

- Interdisciplinary Content of Learning
- Involvement of Students in the Context of Learning
- Active, experiential, inquiry based Process of Education
- Practice of Sustainability
- Partnerships with local, regional communities.
These aspects should be considered while developing the approach. Therefore, the approach will be evaluated and assessed as regards the level of fulfilment of these topics.

The implementation of Sustainability in the context of CDIO Education was discussed in different conference shares. (Cheah, 2014), (Cheah, Yang, & Sale, 2012), (Yang & Cheah, 2014), (Chua & Cheah, 2013) developed an approach for the chemical Engineering, while (Knutson Wedel, Malmquist, Arehag, & Svanström, 2008) and (Enelund, Knutson Wedel, Lundquist, & Malmquist, 2012) faced the challenge in the field of Mechanical Engineering and (Marasco, Moshirpour, Behjat, & Rosehart, 2016) in the field of Computer Engineering. (Hussmann, Trandum, & Vigild, 2010) and (Miñano et al., 2016) investigated on the arrangement of CDIO and Sustainability. These were taken into consideration while designing an approach for the Mining Engineering Courses at Clausthal University of Technology.

For the implementation in the field of Mining Engineering the University of British Columbia developed an approach for the Integration in Education and Research. Interdisciplinary Sustainability Working Groups have a key function in the approach. (Costa & Scoble, 2006)

One educational approach cannot fit whole situation. Teaching must be authentic and needs to fit to the teacher, student and the learning / teaching situation and environment. Therefore, the approaches referred to were used as an inspiration for the implementation at Clausthal University of Technology.

MINING ENGINEERING EDUCATION AT CUT

As one of the oldest mining universities in Europe, founded in 1775, Clausthal University of Technology has a long history in Engineering Education. Starting as a school for mining engineers with courses in mining, metallurgy and mine surveying, later to be supported by courses in mining related law and economics, CUT concentrated on these fields of research and education for nearly 200 years, before expanding the range of courses in the 1960s. Such new courses as Chemistry, Physics, Process Engineering, Mechanical Engineering and Mathematics led to fast rising numbers of students. Thanks to these structural changes, follow-up measures and offering new courses in the following decades, the student numbers increased from about 1000 in 1965 to about 5000 today (2015).

Bridging the gap between tradition and innovation, today Clausthal University of Technology is still strong in education and research in the field of Raw Material Supply and Resource Efficiency. Besides developing innovative methods for the 21st century mine, the aim of the Institute of Mining is to educate engineers who are able to develop and apply up-to-date techniques and to face the challenges of today’s and tomorrow’s global mining industry.

Mining Engineering is an interdisciplinary field comprising the basics of engineering, economy, law and geoscience as well as the special approaches and techniques in Geology, Mining and Processing. In the field of Bachelor’s courses (undergraduate program), CUT offers the Bachelor of Science “Energy and Raw Materials” (German: Energie und Rohstoffe) course. This course is split into the two specializations of “Energy- and Raw Materials Supply” as well as “Petroleum Engineering”. It is designed for a regular study period of 6 semesters (3 years), with German as the language of instruction.
At the stage of Master’s courses, “Mining Engineering” and “Petroleum Engineering” are two fully separated courses. Whereas the language in the Bachelor’s course is German, the Master’s courses are entirely taught in English language, aiming at international students. As it is the case for all Master’s courses at CUT, this course is designed for a regular study period of 4 semesters (2 years). The international character of the “Mining Engineering” course, with about 75% international students with diverse backgrounds, makes education very interesting but also challenging. Depending on their country of origin, the students at Clausthal have diverse previous knowledge as well as diverse experiences stemming from diverse education systems and learning cultures.

In both the Bachelor’s and the Master’s courses, the connection between the disciplines and impacts on environment and society are taught as an aside of the mainly technically and economically orientated study contents and not fixed in the course outline.

For a wider integration of Sustainability in the Master’s course two ways were followed simultaneously. On the one hand, aspects of Sustainable Development were integrated in the usual technically oriented lectures. On the other hand, a compulsory optional lecture was installed to give the students the opportunity to develop their own view of Sustainable Development in Mining. These two lectures are presented in the following sections.

At Clausthal University of Technology Bachelor’s and Master’s Courses are structured in modules which consist of compulsory subjects and compulsory optional subjects. “The compulsory subjects are compulsory for all students for whom the respective module is compulsory. The compulsory optional subject can be selected from various modules.” (Clausthal University of Technology, 2014)

**Advanced Underground Mining – Integration in a technically oriented lecture**

The lecture “Advanced Underground Mining” is a compulsory optional subject located in the third term of the Master’s course Mining Engineering. First realized in the winter term 2016/17 it has 3 ECTS and is taught in 28 contact hours complemented with 62 hours of self-study time. The students participating in this lecture already know the basics of Underground Mining and have in-depth knowledge in Material Handling, Ventilation and Climatization, Underground Mine Planning and Equipment.

After the course the student should be able to:

- link existing knowledge from the different areas of Underground Mining
- communicate their approaches in an appropriate manner with different stakeholders of Mining (Mining Experts, Society, Economists, Ecologists, …)
- act as an Expert for Underground Mining.

In order to achieve these learning objectives, a special concept was designed, which compromises different teaching / learning techniques. The course can be structured in four stages, which are represented in Table 1.

The first stage is a half day-long lecture focusing on a getting to know each other in a personal and technical way. Expectations of students and teachers were identified, compared and discussed, learning objectives were presented. The students were introduced to the project situation where they act as one group of mining experts who should design a new mine nearby. The public acceptance was introduced as a main point of the project. The
objectives of the stakeholders to communicate with were discussed. In the end the students had to decide if they were part of the project group, by naming the group together.

**Table 1. Structure of the Course "Advanced Underground Mining"**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Name</th>
<th>Objectives</th>
<th>Duration</th>
</tr>
</thead>
</table>
| 1     | Getting Started  | • Getting to know the group  
• Understanding the concept  
• Understanding the project situation  
• Forming the project group | 4 hours   |
| 2     | Project work     | • Planning a new mine  
• Preparing for presentation | 3 months  |
| 3     | Presentation     | • Convincing representatives from civil society of their ideas | 1 hour    |
| 4     | Assessment       | • Convincing the technical expert of their ability and skills as an Underground Mining Expert | 20 minutes|

The naming and group formation process introduced the project-based learning phase. In the time period of three months the students had the opportunities to get additional information and feedback on set dates every two weeks using just-in-time teaching. The students had to communicate their needs three days in advance. In cases when the teachers were not informed of any needs, no lecture was given. Additionally, the teachers offered support in personal talks and via email. Technically the students planned the mine and prepared a presentation for their talk to the public.

The third stage is the presentation in front of representatives from the community residing next to the planned mine. The students are free to choose their style of presentation. This presentation is mandatory for completing the lecture, but unmarked. The representatives are real persons from the community as well as university staff with a focus on Didactics and/or mining related topics. For preparation a mandatory trial presentation was conducted.

The Assessment in the fourth stage is a presentation of the students’ concept in a single oral examination. The students have ten minutes to present their approach. Afterwards, questions are asked for deeper understanding. The performance is assessed by using eight criteria, which are linked to the tasks in the project and the learning objectives.

From the CDIO perspective, the students go through the stages of Conceive-Design-Operate-Implement, which differs in detail in comparison to a “classic” product. In the end of the first and the beginning of the second stage the students develop their understanding of the situation, mainly the presentation of a developed approach for mining. They design a solution for mining the deposit as well as communicate with the different stakeholders while linking the present knowledge and skills from other lectures. By setting a presentation concept they implement their strategy. In the presentation and assessment they need to operate.

Aspects of Sustainability are integrated by focusing on the interdisciplinary topic with a clear emphasis on environmental and social consequences.
Sustainability in Underground Mining – Integration through a compulsory optional subject

The lecture “Sustainability in Underground Mining” is a compulsory optional subject. The basic characteristics (CP, hours,…) are similar to the above presented lecture. The learning objectives are:

- understanding sustainability and the importance of it, Current state of art of sustainability in mining,
- providing the basics to lead the students to critically think about sustainability in the mining industry,
- improving presentation skills.

To sum, the goal of the lecture was defined as the students’ having their own critical opinion on Sustainable Development in Underground Mining. For achieving this goal, different concepts and styles were combined and a fitting assessment was developed. These points are presented in the following sequences.

The Learning/Teaching Activities can be structured in three areas as shown in Figure 1.

In the block “Basics and Methods of Sustainability” a basis for the further course is provided in an active learning atmosphere. Different examples directly related to Mining were discussed in certain points to connect the abstract notions with a specific implementation. This block of nine contact hours is conducted in three meetings. Activating Methods are implemented to motivate and involve the students and foster the professional, practical, social and self-competences. The meetings, which are held close to the beginning of the semester, focus also on sensitization and the discussion in the group.

In the second block key notes are held from different stakeholders from the field of mining. After and during the presentation the presented approaches are discussed to link the basic knowledge with the specific mining situation. The structure is variable and can be adapted to different speakers. Besides direct presentation at the university and videoconference key notes there is the possibility to include the visits for conferences and companies into the second block. The flexibility simplifies the realization. The speakers are chosen from different
backgrounds with a special regard on the representation of each stakeholder area as shown in Figure 2.

Figure 2. Stakeholders of Mining Activities

The third block focuses on self-study of the student. He/She reflects on the different meetings and presentations and investigates on one’s own. In the research the students are free to choose their own way. The investigation is supported by allusion to interesting publications in the relevant field. The objective is to help students develop their own critical opinion on Sustainability in Underground Mining. The teacher acts in this block as a coach who answers questions and gives suggestions. Furthermore, the student gets a peer-to-peer feedback in a private poster session.

The achievement of the learning objectives is assessed in an oral examination, simplifying the competence oriented assessment. The process of the assessment is transparent and announced in the first lecture. The assessment is structured in two parts: in the first ten minutes the student accomplishes the sentence “Sustainability in Underground Mining is for me…” and elaborates his/her statement in following time. A prepared poster can be used as a supplement. In the second half the statement is discussed and further question are asked. The examination is assessed by using five assessment criteria, which are the engagement of audience, the methodology, the quality of arguments used, the usage of examples and the style of presentation. This criteria was developed with the students in a feedback session, when they presented their initial ideas. For each grade (very good, good, satisfying, sufficient, not sufficient) explanation is provided. The table with criteria and grading is accessible for all the students.

With regards to the CDIO approach the action Conceive, Design and Implement are performed by the students. First they need to get an impression of the situation and elaborate their own understanding, which is presented in the assessment. In their future career they will perform the “Operate”, acting as a mining engineer with a trained view on Sustainable Development.
Fulfillment of aspects by (Timpson, 2006)

To approve the fulfillment of the above mentioned aspects by (Timpson, 2006), they are compared with the developed approaches. Results are shown in Table 2. All aspects are covered, but there is also potential of improvement. The success of the concept will be shown after the first semester is completed and moreover by means of feedback from our alumni in a few years. Until then the courses will continuously be evaluated and improved on the basis of the evaluation results and experience as shown in the next section.

Table 2. Application of aspects by (Timpson, 2006) in the presented lectures

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Advanced Underground Mining</th>
<th>Sustainability in Underground Mining</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interdisciplinary Content of Learning</td>
<td>Connection of known topics</td>
<td>Diversity of Keynote Speakers</td>
</tr>
<tr>
<td>Involvement of Students in the Context of Learning</td>
<td>Student centered Teaching, Transparency, Constructive Aligned Teaching</td>
<td></td>
</tr>
<tr>
<td>Active, experiential, inquiry based Process of Education</td>
<td>Experiential learning in group and presentation situations</td>
<td>Development of an own view</td>
</tr>
<tr>
<td>Practice of Sustainability</td>
<td>Self-critical development and presentation of an idea</td>
<td></td>
</tr>
<tr>
<td>Partnerships with local, regional communities</td>
<td>Local project framework and audience</td>
<td>Regional Key Note Speakers and Field Trip Targets</td>
</tr>
</tbody>
</table>

EXPERIENCES AND PERSPECTIVES

Both lectures were held the first time with the explained concept in the winter term 2017/2017, which ended in March 2017. Most of the participants have already taken the examination. In the oral examination the students showed constantly a good to very good achievement of the learning objectives.

Different evaluations have been undertaken during and after the lecture. The evaluation of the lecture titled Advanced Underground Mining is mainly based on personal interviews with students and participants of the community talk. During the lecture, feedback was often put directly into practice. At the beginning students often commented that they were not learning anything. In the end they came to realize how to deal with the unfamiliar situation of talking to community members. The participants of the community have also responded positively. An important point, which needs to be improved, is the moderation of the event and the preparation of the participants.

During the lecture titled Sustainability in Underground Mining, feedback was given at each lecture to provide continuous improvement. For the feedback DIN A6 sheets with a plus, a minus and a mouthless smiley were distributed. The students indicated the points they liked the most with the plus and the points which need to be improved with the minus. In addition they completed the smiley with their current mood. The students were mainly in a happy mood after the lecture. They liked the open discussion, collaborative nature, the comforting atmosphere and the discussion with external experts in class. They want to have more details about some topics and more colleagues to discuss with. The experts invited to the sessions enjoyed the discussion with the students as well as the critical questions and views.
While preparing for the examination, which represents the third area with regard to Figure 1, some students expressed that they were facing a new, unusual situation because they were not focusing on the given content. The variety of topics presented in the oral examination shows the diversity of students and sustainability.

In an overall survey, students who visited the mentioned subjects were more likely to identify social awareness and acceptance as the biggest challenge in Mining than the students in the control group, who focused more on environmental challenges.

In the first runs, the concepts seem successful and effective to students, teachers and involved persons. Therefore, they will be refined and applied again in the next winter term. The collaboration with the different stakeholders will be deepened and relevant topics will be picked up. Different parties have already shown interest in supporting the subjects. The main goal of the procedure is to keep the discussed topics relevant and updated. Consequently, the alumni of the Master’s course will be prepared for their role as Mining Engineers of the future.

SUMMARY

The paper shows a possibility of implementation of Sustainability aspects in Mining Engineering education. Sustainability is one of the key future topics not restricted with the field of Mining. Clausthal University of Technology has identified the demand for Mining Engineers who are aware of this aspect. Therefore, the topic was implemented in the curriculum of the Master Program Mining Engineering.

Two course models, which particularly focus on Sustainability, are presented. In the subject titled Advanced Underground Mining, it is integrated in a mainly technically-focused course. The student were asked to achieve the learning objectives within a project, which was accompanied by a just-in-time counseling. The main challenges was the communication with different new stakeholders. The subject titled Sustainability in Underground Mining focuses on the development of an own critical view in the area of Sustainability. In the three stages of the course, the learning format varied. A strong focus is given in an active and collaborative atmosphere.

The first runs in the winter term 2016/17 showed that the students achieved the defined learning objectives very well through the active engagement in the course. Therefore, the concepts will be revised, improved and kept for the following semester.

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REFERENCE LIST


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PEER FEEDBACK IN CDIO COURSES IN ORGANISATION AND LEADERSHIP

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ABSTRACT

Peer feedback is increasingly being used as an important part of higher education, as it has a potential to contribute to development of professional skills such as giving and receiving feedback while having the benefit of not overstretching the teacher resources. In this paper we share our experiences of working with peer feedback in a course on organisation and leadership with approximately 170 students given during the first year of a CDIO-based engineering program. We present and discuss the course design and how peer feedback was organized as well as the experiences of both teachers and students of this course. We observe that working with peer feedback has helped our students in achieving several important outcomes, for example increased learning within the subject, documented development of own writing and assessment skills, and increased awareness of different perspectives on the same topic. However, we also identify problematic aspects of working with peer feedback, such as a large variation in the quality of provided feedback, perceived difficulties when students are asked to provide non-anonymous feedback to their peers, and students’ doubts whether peers can provide as “correct” feedback as the teacher would have been able to give. We discuss the benefits and downsides of peer feedback within the framework of CDIO-based engineering education and conclude by recommending that feedback-related skills should be trained and developed throughout educational programs in a gradual and integrated way.

KEYWORDS

Peer feedback, Course design, Skills development, Active learning, Standards: 8, 11

INTRODUCTION

Feedback on one’s performances is central to any learning experience and can certainly be considered a cornerstone of CDIO-based engineering education. Our students expect and crave feedback on their assignments, and it seems they never can get enough of it. At the same time, providing feedback is time-consuming and resource-intensive, so as teachers we are left with difficult decisions regarding how to work with feedback within limited means. One possibility of extending the amount of feedback provided to our students is working with peer feedback where students themselves provide feedback to each other. However, this needs to be implemented in a carefully designed way and peer feedback activities need to be treated as learning experiences in their own right.
In this paper we will share our experiences of working with peer feedback during a large-scale course with approximately 170 students during the first year of a CDIO-based engineering program. The main topics of this course are organisation, motivation, and leadership and besides these subjects a vital aspect of this course is development of skills such as analysing, critical reasoning, and written presentation. We have recently re-designed this course with inspiration from the work of Kristina Edström and Jakob Kuppenkeuler and their course development (c.f. Edström et al., 2005). Our new design entailed exchanging a previous group writing assignment stretched in time over an entire semester for several short individual writing assignments, ongoing for two-three weeks each where peer feedback was used as a vital part of every assignment.

THEORETICAL BACKGROUND

Peer feedback is increasingly being used as an important part of higher education, as it has a potential to address training & development of professional skills such as giving and receiving feedback while having the benefit of not overstretching the teacher resources (van den Berg et al., 2006 b). Within the CDIO framework peer feedback can be considered as a vital part of “Active Learning” – standard eight, while also being highly relevant for “Learning Assessment” – standard eleven (CDIO, 2016).

Previous studies of peer feedback in higher education suggest that learning activities that include peer feedback foster preparedness for working life insofar as they require the student to formulate feedback independently and accurately as well as to handle incoming feedback in a constructive manner (van den Berg et al., 2006 a). Engaging in peer feedback also creates an arena for reflecting upon and discussing each other’s work, which is positive for the students’ development and confidence (Topping, 1998). Studies also suggest that peer feedback might be equally good as or even better than teacher assessment (Topping, 1998) – perhaps due to a higher degree of carefulness that can be applied when the students work with feedback on a smaller number of texts as opposed to a teacher’s workload. This has been noted by van den Berg and others (2006 b) as they observe that peer feedback means receiving more feedback sooner than when provided by a teacher.

However, others note that peer feedback can also lead to problems with varying quality of comments and suggestions received, differences in assessment between peers and teachers, as well as fear of being plagiarised by one’s peers (Pearce et al., 2009). Problems can also arise with regards to different interpretations of the assessment rubrics as suggested by Boase-Jelinek et al (2013) that observed that even detailed explanations of the rubrics were not enough to eliminate misunderstandings between the teachers’ intentions and students’ interpretations. Furthermore, students can be confused when peer feedback generates contradictory suggestions, and can experience that they are not getting any valuable feedback on their work, while simultaneously doubting their own capability with regards to providing feedback to others (Sweetland Center for Writing, 2016).

Several authors have proposed specific methods of working with peer feedback that strive to address the potential problems that can arise. For example it is suggested that peer feedback should be organized in small groups of up to four students and that a combination of written feedback and a following face-to-face discussion leads to a more complete feedback (van den Berg et al., 2006 a). It has also been proposed that a structured review form can be useful for guiding towards specific aspects that the feedback should address.
(Pearce et al., 2009), preferably in the form of open-ended “how” and “why” questions (Sweetland Center for Writing, 2016).

**The teacher’s role in peer feedback learning activities**

Organizing peer feedback activities means that the traditional role of the teacher shifts from lecturing and providing all the answers to facilitating students’ own learning. Cooper (2002, p. 56) characterizes this as a “shift in focus from what is being taught to what is being learned”. This should not be confused with a passive role of an observer, and initially often requires investing time and effort into making the transition (Finlay & Faulkner, 2005). In previous studies of peer feedback activities it has been observed that involved teachers sometimes experienced that their role was not clear enough and that teachers wished for more time and opportunity to provide students with support when giving feedback (van den Berg et al., 2006a). The shift in focus implies concentrating on matters such as how to design the activities so that they are rewarding for students, how to explain what type of feedback the students should aim to provide, and how to create a safe atmosphere so that students are willing to share their own texts and their comments on texts written by others (van den Berg et al., 2006b). It should also be noted that the surrounding academic leadership at the departmental level and collegial support impacts how active learning and activities such as peer feedback can be implemented and what outcomes can be achieved. The teachers’ approach to teaching and learning in turn impacts how the students view their studies and their own roles (Ramsden et al., 2007).

**Relation between teacher and students in peer feedback learning activities**

The students’ learning outcomes are dependent on their own conceptions of learning and their approach to learning as well as their perception of the learning environment (Trigwell et al., 1999). Additionally, it has been shown that the teachers’ own approach to teaching is correlated to whether the students adopt a surface or a deep learning attitude towards learning in specific contexts where the teacher is involved. For example, an “information transmission” approach of a teacher is related to surface learning approach of students while a “student centred” approach is related to more engagement and deeper learning (Trigwell et al., 1999). Peer feedback activities can be considered as one possible way towards transforming the roles of teachers and students and how they are supposed to relate to each other (van den Berg et al., 2006b).

**METHOD**

Experiences from working with peer feedback that are presented in the next section are derived from a course given at Linköping University during Spring 2016. The pedagogical development of the course has been supported by a small grant from the Institute of Technology at Linköping University. The teacher team consisted of the two writers of this paper and one more teacher. Teachers’ experiences have been recorded in writing during the course and shared and reflected upon during meetings continuously throughout the course. The students’ views have been collected through anonymous questionnaires four times during the course and have formed an important input into the teachers’ discussions and continuous improvement of the course design. During several of the teacher meetings an external discussion partner from the university pedagogical center Didacticum has participated and provided valuable input.
Students’ views on peer feedback that are presented below have been collected during the last activity of the course, after the last assignment was completed. 78 students participated in this activity and all of them answered our open-ended questionnaire about the course design. The following questions were asked:

1) What has been the most positive with the course design?
2) What can be improved?

The questions were open-ended without any given keywords or alternatives to choose between. The responses were categorized by the course teachers. Of the 78 respondents 38 students spontaneously mentioned peer feedback in their answers. Half of the students who mentioned peer feedback were critical of the peer feedback “elements” in the course and the second half was positive or expressed both positive and negative attitudes.

RESULTS

The design of peer feedback activities and teachers’ experiences

During the course students worked on five assignments, the first being a visualisation of own time planning with regards to the course activities in a Gantt chart and the other four being short texts (1-3 pages) on given topics. For each of the four writing assignments the students received feedback in three ways, see Figure 1. Firstly, each student received extensive written peer feedback from a few of their classmates; secondly, assignment texts were awarded points by the teachers (0 points for incomplete submission, 1 point for “good enough” text, 2 points for excellent text); and thirdly, the teachers provided group feedback where we pointed out common problems in the texts and displayed good examples.
Peer feedback was given during four separate classroom sessions, lasting for 90 minutes each, one for each writing assignment. The participation in these sessions was voluntary and active participation added credits to the total for the course segment. In order to pass the segment a fixed amount of credits was required meaning that collecting a lot of credits in the beginning of the course lead to a quicker completion of this segment.

Each student was required to bring a printout of his or her text for the current assignment to the feedback session. The texts were collected by the teacher in the beginning of the session and distributed randomly to peers. Approximately 15-25 students participated in each single session (the 170 course participants were divided into several classes). Thereafter time was given to read and give written feedback. Each student was given at least two different texts and consequently received feedback from at least two peers. When giving feedback the identities of the reader and the writer were known to both. In the end of the session each student was given their own text and written peer feedback from all readers and time was allowed for reading and reflecting upon the received comments as well as documenting received feedback by taking a photo. Both the text and the feedback were then returned to the teacher in order to be graded (the text for the assignment could receive 0, 1 or 2 points and this grading was done solely by the teachers). Finally the students filled out a questionnaire in the end of each feedback session with questions concerning learning from writing as well as from giving and receiving feedback on the current assignment.

Since every text was supposed to be in its final version at the feedback session it was important that the peer feedback focused on aspects that could be applied to forthcoming assignments as well as future writing in general. In the beginning of the first feedback session a guide on giving feedback was distributed to the students, specifying among other things the questions that peers should address in their feedback, e.g. how easy it is to follow.
the reasoning in the text. We noticed that having this guide was not supportive enough and that most students did not address all the questions given in the guide. They focused instead on minor details that were instantly recognizable such as spelling errors. After the first session we discussed this during a teachers’ meeting and consulted the literature. We decided to provide students during the following feedback sessions with structured forms with specified areas on which feedback was supposed to be given. This was much appreciated by the students and steered them towards providing more comprehensive and nuanced feedback. However, we still experienced problems related to differences in interpretation of feedback criteria/assessment rubrics and we found it challenging to explain all criteria that we encouraged the students to apply.

We also experienced that most students were positive towards peer feedback in the beginning during the first assignments but became more negative towards the end of the course. Moreover, we experienced that many students found it problematic to give accurate feedback without being anonymous – they told us that they tended to hold back on their criticism when it was known who gave feedback to whom. As future leaders and engineers it is important to be able to deliver feedback in a professional and open manner so we decided we would not make peer feedback anonymous, and instead explained the significance of providing feedback as a professional skill.

Students’ views on the peer feedback activities

As mentioned above, approximately half of the students who spontaneously mentioned peer feedback in the final questionnaire were critical and half of the students were positive or expressed a mix of both positive and negative attitudes towards peer feedback within the course. Among the positive responses we noted that several students perceived that working with peer feedback increased their learning. For example they reported that they learned how to give feedback and became better at it throughout the course and they also appreciated the practice. See Table 1 where students’ positive comments about peer feedback from our questionnaire are summarized.

<table>
<thead>
<tr>
<th>Giving feedback to others</th>
<th>Receiving feedback on own text</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Development</strong></td>
<td><strong>Positive to get comments continually</strong></td>
</tr>
<tr>
<td>Educational, learned how to give feedback</td>
<td>Useful to receive feedback</td>
</tr>
<tr>
<td>Being able to practice giving feedback was good</td>
<td>Feedback has stimulated development</td>
</tr>
<tr>
<td>Rewarding to provide feedback to others</td>
<td>Receiving feedback has been fun</td>
</tr>
<tr>
<td>Became better at giving feedback</td>
<td>Several opportunities to get feedback and learn</td>
</tr>
<tr>
<td><strong>Benchmarking</strong></td>
<td><strong>Improved my general way of working</strong></td>
</tr>
<tr>
<td>Insight into someone else’s thoughts</td>
<td></td>
</tr>
<tr>
<td>Seeing several ways to write the same assignment</td>
<td></td>
</tr>
<tr>
<td>Reading about how others interpret concepts/theories</td>
<td></td>
</tr>
<tr>
<td>Broader perspective when you read others’ texts</td>
<td></td>
</tr>
<tr>
<td>Get several perspectives</td>
<td></td>
</tr>
<tr>
<td>Fun to read others’ texts</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Positive attitudes towards peer feedback in course design questionnaire
Several students also appreciated the benchmarking aspect of reading other students’ texts. They got insight into other students’ ideas; they saw several different ways to write and how others comprehended concepts and theories. They also got a broader perspective on the topics covered by the assignments through reading other students’ texts. Peer feedback, criticism and comments were perceived by several respondents as fruitful, useful and stimulating and inspired the students to improve their way of working. The quotation below illustrates this:

“Above all, the peer feedback sessions have been very rewarding. Both to read others and reflect on what could have been done better, but also to get feedback directly on own texts from people who are in the same position as you. This gives you a direct and good understanding of what you, by yourself, think is a good text.”

Half of the students that spontaneously mentioned peer feedback in their answers did not discuss the opportunities described above at all, instead they only reported on the downsides of peer feedback. They suggested that they would rather receive more feedback from teachers, that the peers could be too inexperienced to give feedback, and they were critical to the feedback system and the overall way of working, see Table 2.
Table 2. Negative attitudes towards peer feedback in course design questionnaire

<table>
<thead>
<tr>
<th>Other students’ feedback perceived as not useful</th>
<th>Prefer more feedback from the teacher</th>
<th>Way of working</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Many peers are not good at giving feedback</td>
<td>• More clear feedback from the teachers</td>
<td>• I need to know how important each part of the text should be, would like more introduction to the disposition of the texts at the beginning of the course</td>
</tr>
<tr>
<td>• Maybe the feedback I receive is wrong</td>
<td>• Would like to know from the teacher what is missing for the excellent level</td>
<td>• Would like to be able to take home a corrected version of my text</td>
</tr>
<tr>
<td>• Since my peers have the same knowledge the feedback I get from them is useless</td>
<td>• Teacher feedback is needed in order to learn from own mistakes</td>
<td>• I didn’t take the course design seriously since I perceived the setup as unserious</td>
</tr>
<tr>
<td>• I get nothing from the feedback provided by peers</td>
<td>• More comments on my text from teachers</td>
<td>• Possibility to receive extra credits for the final exam would give me more motivation</td>
</tr>
<tr>
<td>• Difficult to know what I should improve in my writing</td>
<td>• The teacher should tell me what I have done well and what was less good. I have no idea what I could have done differently in order to write a better text</td>
<td>• When I read others’ texts I don’t know if the text is good or bad and may draw the wrong conclusions. I would rather first read the teacher’s feedback and then give my own</td>
</tr>
<tr>
<td>• The feedback I received was not always “correct”</td>
<td>• I would like to receive feedback along with the grade on the assignment</td>
<td></td>
</tr>
<tr>
<td>• I don’t know if I can trust peer feedback since the subject is new for us</td>
<td>• A grade is not enough assessment from the teacher</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• The person giving the text the grade should provide feedback</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Teacher feedback is interesting when a text can get different grades</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Even short individual feedback from teachers would have been rewarding</td>
<td></td>
</tr>
</tbody>
</table>

According to the negative student comments, the students perceived that they did not get the “correct” peer feedback, and they could not trust the feedback they received, therefore they felt that they did not know what to improve in their texts, especially when aiming for higher points. The following two quotations illustrate this further:

“I would have appreciated some comments from the professor so that I would know if I was close to fail or to excellent level. The other students possess same knowledge and the feedback thus becomes quite useless.”

“If I had received feedback from the teacher I would have improved myself from good enough level to the excellent level.”
CONCLUSIONS AND DISCUSSION

Overall we have experienced that this course design has helped our students in achieving several important outcomes, namely increased learning within the subject, documented development of own writing and assessment skills, and getting to know different perspectives on every assignment through reading several texts written by peers. Furthermore, students have gained insight into how difficult and time-consuming it can be to give feedback to others. Through the course design the students have also started to develop a familiarity with sharing their work and their opinions of others’ work among peers – something that will be essential in their further education and later on in their professional development.

Some of the challenges we discovered during the course presented here included difficulties with giving peer feedback when supported only by guidelines and questions provided by us. This was addressed through development of “feedback forms” that gave more structure to the peer feedback. The inspiration for this came through reading up on previous studies on peer feedback and the positive outcome has encouraged us to try out other ideas provided in the literature in the future, e.g. combining written and oral feedback during a feedback session.

The large variation in quality of feedback provided by peers was experienced as problematic, both by the students themselves and by us teachers. However, we noticed that students that were given the peer feedback task as “homework” instead of performing it in the classroom in most cases managed to produce feedback of higher quality. This implies that more time and possibility to work in a more comfortable setting can lead to improvements in the overall quality of peer feedback. Literature also suggests working with calibration exercises in order to address feedback quality issues, e.g. reading and giving feedback on the same text initially and comparing and discussing the results with the students as a way of clarifying how feedback can be provided. This could also prove supportive for critical evaluation of own texts. As seen in Table 2 some students expressed that it was difficult for them to know what was good and what could be improved within their own texts which signals problems with self-assessment. Nonetheless, some degree of variation is a normal part of working with feedback and should be expected; this could be better explained to the students during the course along with a discussion on subjective and objective aspects of feedback.

We were surprised by the strong preference for anonymous feedback from several students. Their argument was that anonymity allowed for more honest feedback. We are convinced that non-anonymous feedback is preferable from a learning and skill development standpoint. However, the students’ requests for anonymity could be interpreted as a symptom of not feeling safe enough within their class, a problem that is indicated in the literature and that could be addressed in other ways by us teachers. Another aspect that surprised us was that feedback provided by the teachers through awarded points for each text, along with group feedback that identified common problems in students’ texts and displayed good examples, was by many perceived as not enough. The system with 0 points (signifying fail); 1 point (signifying good enough); and 2 points (signifying excellent) for each text was by our students perceived more as a source of frustration than of valuable feedback. During the next edition of this course (given in Spring 2017) we have opted for limiting the grade scale to only the grades pass or fail on each text and we will be working with development of our communication regarding how our feedback relates to the individual students.

Working with peer feedback and active learning definitely strikes at the core of the various roles of teachers and students in higher education as discussed in the theoretical
background. The attitudes of students presented in Table 1 and 2 can be related to how the students perceive their own and their teachers’ roles in the learning process. Some of our students seem to view the teacher as the “oracle” that should be the one providing all the answers. Since the teacher is the one awarding points only the feedback from the teacher is perceived as potentially useful by these students. Other students instead perceive peer feedback as useful and appreciate being given the opportunity to reflect upon the work of others and to express their opinions to their peers without being supervised or corrected by the teachers. Attitudes and expectations with regard to teachers’ and students’ roles can certainly be influenced during one course but they are also shaped by all the other educational experiences an individual goes through. Therefore the context of the educational program should be considered and to the highest degree possible aligned around common goals with regard to the approach to learning, as well as development of knowledge and of professional skills.

In conclusion we propose that both giving feedback and receiving/making use of feedback are vital skills that increase capability for learning and are required in virtually any future professional role. Development of these skills needs to be supported, as many students consider peer feedback to be difficult and many lack the confidence in both their own and their peers’ abilities to give feedback. We recommend that feedback-related skills should be trained and developed within CDIO-based education in a gradual and integrated way.

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BIOGRAPHICAL INFORMATION

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ENGINEERING AND OCCUPATIONAL THERAPIST STUDENTS IN DESIGN PROJECTS – CROSS-DISCIPLINARY MEETINGS

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Department of Management and Engineering, Linköping University

ABSTRACT

Engineering students need to develop their abilities to communicate their ideas in cross-disciplinary situations. This paper presents the results of a longitudinal inter professional teaching activity involving collaboration between engineering and occupation therapist students in design projects at Linköping University, Sweden. The objective of this paper is to share and reflect on experiences of integrative teaching activity in a course in Product Ergonomics for engineering students in Design and Product Development. The paper is based on the engineering students’ evaluations, interviews with teachers and the authors’ own experiences of the teaching activity. The course consists of two parts, a theoretical part and an applied product development project. During the project, the students are trained to develop and present credible product concepts. In this phase, the engineering students meet with occupational therapist students at the Faculty of Health Sciences. The engineering students then learn and benefit from the other students’ knowledge fields. They also train to communicate with other disciplines and are able to demonstrate their engineering skills, the latter when they reflect on in parallel ongoing design projects undertaken by the occupational therapist students. As a result of the meeting with the occupational therapist students many engineering students modify the direction of their design project. The engineering students also receive good advice on how to approach and learn about the user of the product that is to be designed. Some issues that need to be taken into account for the integrative teaching activity include the timing for the meetings between the student groups, number of meetings and how to prepare the students.

KEYWORDS

Product development, Ergonomics, Communication, Collaboration, Standards: 2, 3

INTRODUCTION

Product development is characterized by integration, both technical and organizational, where the latter refers to integrating different organizational functions in the development process (Johannesson and Persson, 2004). These functions in are for instance marketing, construction, sales, and production. Studies show that collaboration between people with different backgrounds is essential and to develop high-quality products (Wind and Mahajan, 1997). Research on new product development (NPD) also highlight the importance of developing co-development alliances on an organizational level (Emden et al, 2006) and
cross-functional teams within and company sites are common (Ulrich and Eppinger, 2012; Andreasen and Hein, 1987). It is therefore important for engineering students to develop their abilities to communicate their ideas in across disciplines situations. This implies training the engineering students to communicate their own ideas to groups outside the university, but also encouraging them to learn the need and benefits of collaborating with other groups. In future work, the interpersonal skills may even outweigh a technical curriculum in some cases (Bhavnani and Aldridge, 2000).

In research, collaboration across disciplines has been encouraged since at least the second World War (Williams, 1946). The experiences from these undertakings have been both positive and negative. In order to work efficiently, a general conclusion is the need to manage resources and create an understanding for each other’s disciplines (Blackwell, 1955; Stemper, 1991). Costs increase due to a need for project coordination, administration, and travels. Researchers from the different fields also need to harmonize epistemologies, create rules for cooperation as well as decide methods for research and research goals. Stemper (1991) further puts forward that working across disciplines in both research and teaching can be conducted in five ways; intra-disciplinary, cross-disciplinary, multidisciplinary, interdisciplinary, and transdisciplinary.

Stemper (ibid) states that intra-disciplinary is the easiest form of collaboration and stands for when teachers and researchers are working within one discipline, for instance teaching subthemes, such as math and thermodynamics, to mechanical engineering students. Cross-disciplinary stands for working between two disciplines with the same theme, as in this study where engineering and occupational therapist students work with developing products from an ergonomic perspective. Multidisciplinary is a higher level of cross-disciplinary collaboration, which aims at working with several disciplines in one research project or study program to provide different perspectives on the same subject. In interdisciplinary cooperation, the partial contributions of the different disciplines are integrated to create a coherent whole or a general concept. Finally, the highest level in Stemper’s (ibid) ways of collaboration is transdisciplinary collaboration, which is described as “the unity of intellectual frameworks beyond the disciplinary perspectives”.

This paper presents the results of a longitudinal teaching activity involving collaboration between engineering and occupational therapist students in design projects at Linköping University, Sweden. The objective of the paper is to share and reflect on the experiences of the cross-disciplinary teaching activity in a course in Product Ergonomics for engineering students in Design and Product Development (DPD). The reported experiences are from a six-credit course in Product Ergonomics. It is a compulsory course for third year students in the engineering program Design and Product Development.

The DPD program has been developed to meet demands on future engineers to be able to solve technical and functional problems as well as usability issues, and it includes classical engineering subjects such as Mathematics and Engineering as well as e.g. Ergonomics, Industrial Design and Interaction Design. The goal is to educate creative product development engineers who have a human centered approach (ISO-standard, 2010) and an understanding of aesthetic values when developing new products and services.

In the subsequent chapter, the method for this paper is described, followed by a description on how the collaboration between mechanical engineering and occupational therapy was developed. The course Product Ergonomics, within which the collaboration takes place for the engineering students, is then described. This is followed by experiences of the
collaboration from the students’ and teachers’ view respectively. The paper ends with a discussion about experiences, advantages and challenges, and a final conclusion.

METHOD

Data for this paper were collected through questionnaires in which the engineering students’ evaluated the cross-disciplinary meetings during four years, see Table 1. The questionnaire topics included the perceived importance of the meetings, learning by the engineering students, and improvement suggestions.

Table 1. Evaluation questionnaires to engineering students

<table>
<thead>
<tr>
<th>Year</th>
<th>No of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>58</td>
</tr>
<tr>
<td>2014</td>
<td>43</td>
</tr>
<tr>
<td>2015</td>
<td>56</td>
</tr>
<tr>
<td>2016</td>
<td>54</td>
</tr>
</tbody>
</table>

Data were also collected through semi-structured interviews with three teachers (two from engineering and one from occupational therapy) who initiated the collaboration between the engineering and the occupational therapist students. Interview topics were the background to the collaboration, experienced positive outcome and challenges.

The paper is also based on the authors’ own experiences of being teachers and/or examiners during five years in the Product Ergonomics course.

DEVELOPMENT OF COLLABORATION BETWEEN MECHANICAL ENGINEERING AND OCCUPATIONAL THERAPY

In spring 2003, the Mechanical Engineering board of directors at Linköping University, Sweden, made a decision that a new five-credit project course named Product Design should be developed and start during the fall in the same year. Two teachers at the division of Machine Design were assigned to develop the course, and as a theme they selected "Tools for Veterans". The idea behind this project theme was to develop aids and tools for elderly people with disabilities. Due to the chosen theme, a contact was initiated with the Occupational Therapist program (OT) at the faculty of Health Sciences at Linköping University. Occupational therapist expertise is to adapt environments to people with disabilities thereby facilitating for them to work and have meaningful daily activities. The contact at the OT program was very positive and this developed in to a course collaboration where engineering and occupational therapist students cooperated in product development projects and teachers giving lectures to respective student group. The aim of this integrative teaching activity was that the students should (Kjellberg et al, 2006):

- Gain insight and knowledge in the area of design and human factors
- Identify and analyze problems close to the reality from user’s perspective
- Achieve the ability to develop alternative and creative design solutions starting from a problem formulation
- Develop a reflective attitude towards “design for all”
• Be able to evaluate different design qualities

The collaboration was designed in such a way that both faculties had their own courses and the two student groups had joint projects. This setup made it possible to avoid administrative difficulties such as student registration and course funding.

The mechanical engineering students contributed with their knowledge in mechanical design and the occupational therapists with their knowledge in human needs focusing on elderly people. The course was very popular from the start, and approximately 50 to 60 engineering students applied for the Product Design course and 20 to 30 OT students chose OT’s product development course. The project groups where selected so that two thirds were engineering students and the rest OT students. In its final design, the course curriculum focused on product development, basic industrial design skills and basic physical ergonomics.

The collaboration is still ongoing but has developed over the years. The first development occurred after two years when the OT program moved from campus Linköping to campus Norrköping, which is situated 46 kilometers away. The OT program also went through an extensive curriculum change toward a Problem Based Learning (PBL) educational philosophy. The introduction of PBL changed the OT students’ schedule from having several courses in parallel to having an integrated course that extended over the full semester. The machine engineering students’ curriculum remained the same. These two major changes made it more difficult to synchronize course schedules. The distance between the two campuses, 35 minutes by campus bus, made it more difficult for the OT and engineering students to meet up in their project groups and plan project tasks. The changes lead to a more scheduled collaboration where the OT students initiated the projects by giving the engineer students a user problem and then only participated in evaluating concepts and the final results.

The second major change occurred in 2011 when the Product Design course was cancelled due to curriculum changes for the engineering students. Both the OT teachers and the engineering teachers wanted to maintain the collaboration between the faculties. A decision was therefore made to move the collaboration to a compulsory Product Ergonomics course at a newly formed Design and Product Development program (DPD), which had started in 2008. The DPD program is an engineering program but has an industrial design and human-centered focus in the curriculum. New teachers from the Product Ergonomics course were involved in the collaboration, which was slightly changed again as the course content in for both student groups had changed. The DPD students now had to investigate user needs as a task in the Product Ergonomic course, while at the same time OT teachers had initiated a product development task in the separate course for the OT students, named Work Therapy in a Surrounding World Perspective. In the prior course, Product Design, the knowledge polarization had also been greater between the different student groups, thus rendering more distinct and clearer project roles. Mechanical engineering students focused more on the technical part of the project and the OT students on human needs. This second change influenced the collaboration into being more structured and distant. Students from the different programs got a consultant role to give feedback on each other’s projects.
THE COURSE PRODUCT ERGONOMICS WITHIN DESIGN ENGINEERING

The six-credit course is designed to introduce the field of ergonomics and design and provides a basic ability to evaluate the applicability of ergonomics design as a methodology. It runs during the full autumn semester, and it consists of two parts: a theoretical part and an applied product development project. The learning outcomes of the course are related to several CDIO standards, of which the last is highlighted in this paper. After the course, the students should be able to:

- use some ergonomics theories and principles in product development (CDIO 1.1, 1.3, 2, and 4)
- use some qualitative and quantitative methods to understand the user’s needs and requirements (CDIO 1.3, 2.1, and 4)
- assess and evaluate the consequences of ergonomics in products (CDIO 2 and 4)
- analyze and examine the role of ergonomics by discussing and evaluating different products and product development questions (CDIO 1, 2.1, 4.1, and 4.2)
- communicate with other disciplines, acting professionally as engineer in a multidisciplinary context and presenting product concepts in a credible way (CDIO 2.5 and 3.1)

During the theoretical part, the students learn concepts, models, and methods used in Ergonomics. Ergonomics is a multidisciplinary field (Wilson, 2000, 2014), and the course is therefore divided into weekly themes, see Table 2. Each theme is addressed in lectures, group assignments, and seminars.

Table 2. Themes within Ergonomics in the course

<table>
<thead>
<tr>
<th>Theme</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anthropometry</td>
<td>The anthropometry theme focuses on strategies to use when developing a product for a human body, what data to extract out of an existing anthropometric data set and how to create own data sets. The theme consists of one workshop assignment. During the workshop, data sets from <a href="http://antropometri.se/">http://antropometri.se/</a> and anthropometric measuring methods are used by the students to investigate a case.</td>
</tr>
<tr>
<td>Biomechanics</td>
<td>The biomechanical theme concerns loads applied to the body when undertaking a task and their effect on the body. Different methods to assess the risk for injuries are studied, e.g. biomechanical calculations, NIOSH lifting equation, and Snook tables.</td>
</tr>
<tr>
<td>Cognitive Science</td>
<td>The theme focuses on the importance for the product developer to take into account the users’ cognitive limitations and differences, to create affordance and facilitate for the user.</td>
</tr>
<tr>
<td>Physical Factors</td>
<td>Physical factors include thermal climate, sound and vibration, light and radiation. These relate more to Ergonomics of production than to Ergonomics of products but are still an important part of the engineering profession. The content covers physiology, physics, the industrial environment, assessment, prevention and legislation.</td>
</tr>
</tbody>
</table>
The systems perspective is emphasized through the introduction of the HTO-perspective, which highlights the interaction between the components humans, technology and organization. The students are assigned a task to reflect on an accident scenario and explain the background to the accident from an HTO-perspective.

During the second part of the course, the applied product development project, the students develop and present credible product concepts. The project aims at consolidating the students’ understanding by implementing the theoretical knowledge in a relevant context. It constitutes an arena for developing practical skills in applying the theory and methods. In the project, the students have a wide choice of possible products to develop. The only instruction they receive is that they are to develop a concept for an everyday product used in a specific situation for a user with limited temporary or permanent capabilities.

In the project phase, the engineering students meet with occupational therapist students at the Faculty of Health Sciences. The DPD students then learn and benefit from the occupational therapist students’ knowledge about users with special needs and methods to investigate these needs. The DPD students also train to communicate with other disciplines and are able to demonstrate their engineering skills. The latter is practiced when they reflect and give advice on the occupational therapist students’ design projects, which take place in parallel with the engineering students’ projects. As mentioned before, they apply a consultant role to each other, where the engineering students give advice on the technical aspects of a design solution, models and materials. The occupational therapist students, on the other hand, act as consultants regarding human activity in a certain context. The number of meetings between the engineering and the occupational therapist students vary from one year to another, from one to three meetings.

CROSSDISCIPLINARY MEETINGS – EXPERIENCES

Engineering students’ view on the collaboration

The Design and Product Development students had mixed experiences about the collaboration. They put forward that the occupational therapist students possessed good knowledge about areas, in which the engineering students were lacking, for example about rheumatism, and that OP students could transfer their way of focusing on the user. The DPD students also appreciated the OT students’ open way of thinking (not being attached to a common technical way of thinking). Perhaps a new product would not be a solution to a certain problem as there already existed different products on the market.

The OT students gave the DPD students new perspectives, for instance experimenting with themselves to test how it is with a certain lack of body functionality. They also gave the DPD students better overview of their problem area and how the users could be interviewed. The engineering students also put forward the importance of working with other professions, which was expressed as:

"Nice initiative to work with other professions. Nothing we have done before and which was relevant and important."
Some students did not appreciate the collaboration, stating that it should be voluntary for the groups who were in need of collaboration with the OT students, and that it would have been more efficient to spend the time on project work. In some cases, the students also experienced that they had too little knowledge when meeting the OT students, and that it was difficult when the student groups were in different phases in their projects. Some students also perceived that there was lack of preparations from both student groups before the meetings.

The Design and Product Development students further put forward some suggestions for improvement of the collaboration between the engineering and the OT students:

- More time for collaboration, to present the projects and help each other (and that it would be easier if all students studied at the same campus)
- It is good if the student groups’ projects are in the same phase when the students meet
- It is important to clarify what is expected from the students except working cross-disciplinary
- Questions from one student group to another should be sent between the groups in advance
- Creation of joint project groups consisting of a mix of engineering and OT students as the OT students have knowledge about humans and the engineering students have knowledge about technology and product development

**Teachers’ view on the collaboration**

The teachers also experienced both advantages and challenges with the cross-disciplinary meetings. The OT teacher put forward that the students learn about their own competence and the other students’ competencies. By that, they receive better preparedness to face challenges in a changing society. One of the engineering teachers also pointed out that the DPD students learn about human needs that are not covered by the course book, and that they therefore have to collaborate with students from another field.

As a result of meeting with the occupational therapist students many engineering students modified the direction of their design project. The DPD students also received good advice on how to approach and learn about the user of the product that is to be designed. This was a clear positive outcome of the collaboration. It was also valuable with the teacher collaboration and learning about each other’s discipline and courses.

One challenge from a teacher’s view was the distance between the two campuses, which hindered an easy face-to-face group collaboration. The travelling between the campuses with whole student groups influenced the number of scheduled meetings between the students, down to only one scheduled meeting throughout the course. Some other issues that needed to be taken into account for the integrative teaching activity included the timing for the meetings between the student groups in relation to the design processes in their respective courses and how to prepare the students for the meetings.

Even though there were challenges to face, the AT teacher listed lessons learnt that could be of use in future integrative teaching activities:

- Personal meetings between teachers are important to identify touch points regarding competencies and within the different educational programs
• Keep the overall aim in mind – to prepare to students for a working life outside the university – and what is relevant to society
• The collaboration will vary over the years, avoid expensive common educational program plans
• Work in an informal way, start quickly, experiment and evaluate
• Focus on possibilities and keep an open dialogue with the students about preconditions for the collaboration

DISCUSSION

From the beginning the collaboration has had an integrated product development approach where the different student groups have clearly defined functions, or knowledge areas, as well as separate management structures (teachers and curricula) that must interact. This made it possible to create a collaboration scenario where the students met new knowledge cultures, different ways of solving problems, and management problems such as planning and communication issues. Thus, the collaboration relates to implementation of the CDIO Standard 2 and 3 (Section 3).

The design of the integration was challenging for the students and they had both positive and negative experiences. Positive as they discovered their own competence areas, learnt new ways of challenging their problems, and gained knowledge that was not included in the curriculum. The reported negative experiences were mainly related to how the management was managed after the change when splitting up in separate projects. The different student projects where then not coordinated so that they had the same user need or problem to solve, and the scheduled meeting time was perceived as too short.

From a teacher’s perspective, the interviews showed that the engineering students were challenged to do something they were not used to and that they were mostly positive towards the meetings with the OT students. They also shifted their perspective on their chosen problem towards a more complex understanding, and they understood the need to explore user needs profoundly.

The authors also acknowledge that some further improvements can be done, such as coordinating the project tasks and course schedules so that the students more easily can exchange knowledge and experiences.

When setting up a cross-disciplinary collaboration it must be a win-win situation for both teacher and students alike to build a lasting relationship. This is in line with earlier reports about multidisciplinary courses, where it is important that all stakeholders (students, faculty, and administrators) benefit from the collaboration (Lovejoy and Srinivasan, 2002). The collaboration has been between two courses, not a joint one, implying that no faculty has had an economic influence over the other and there is no absolute obligation toward one another. The history of the cross-disciplinary collaboration demonstrates the need to be flexible and adapt to changes in both curricula and planning to maintain it. Overcoming administrative hurdles such as schedules, budgets, and facilities should be a priority. This paper has described the evolution of over 14 years of course collaboration between engineering and OT students and how it has influenced the learning outcome of engineering students that have participated in the courses.
According to the authors’ experiences it is important to determine the level of epistemological and curriculum integration between the disciplines. In the lower levels of cooperation, such as intra-disciplinary, cross-disciplinary, and multidisciplinary, the epistemological integration is lower thus creating less potential friction between coordinating teachers. Depending on the course budget and faculty support, the curriculum integration may vary from no integration to a common schedule with joint grading. Interdisciplinary and transdisciplinary on the other hand creates a need for a full coordination of the different disciplines and also a need to create a common understanding of learning goals, joint grading and best practice to reach final results (Lovejoy & Srinivasan, 2002).

CONCLUSIONS

This paper describes a long-lasting teaching collaboration between the Faculty of Science and Engineering and the Faculty of Health Sciences at Linköping University, Sweden. The collaboration involves meetings between engineering students and occupational therapist students during in parallel ongoing design projects in separate course. They then train to communicate across disciplines and act as consultants. The engineering students give advice on the technical aspects of a design solution, models and materials, while the occupational therapist students act as consultants regarding human activity in a certain context. Some challenging issues that need to be dealt with include the timing for the meetings between the student groups, number of meetings and how to prepare the students.
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MODIFIED CDIO FRAMEWORK FOR ELEMENTARY TEACHER TRAINING IN COMPUTATIONAL THINKING

Stephanie Hladik, Dr. Laleh Behjat, Dr. Anders Nygren
Electrical and Computer Engineering, University of Calgary

ABSTRACT

Computational thinking involves designing systems, finding solutions to problems, and understanding human behaviour through computer science concepts. Recent reports call for the inclusion of computational thinking in elementary (K-6) education, but there are barriers including a lack of teacher knowledge and confidence in the subject, and in Canada, a lack of a nationally-defined curriculum. Computational thinking is often taught outside of the formal educational system, and in some cases, alongside engineering design concepts. This provides an opportunity to use the CDIO framework to teach computational thinking. While the CDIO framework is designed for post-secondary engineering programs, it has been successfully used at the K-12 level, though it must be adapted and simplified for use at the elementary school level. This paper breaks down each of the Conceiving, Designing, Implementing, and Operating steps in the CDIO Syllabus to analyze and compare them against computational thinking and programming frameworks. This information is then used to adapt the C-D-I-O steps to teach computational thinking concepts to university level students in education and in-service teachers. The proposed technique provides a framework for teachers to create their own computational thinking activities at the elementary level, and for students to move through the steps as they complete such activities. This paper details the creation and use of the new framework, beginning with the existing CDIO framework and its modifications to be applicable for K-6 computational thinking activities. It also includes the design of a computational thinking activity using the new framework, and an example of working through that activity. Finally, it briefly details future work, such as other activities and their use in a professional development workshop for teachers.

KEYWORDS

Computational thinking, design thinking, K-12, C-D-I-O, Standards: 1, 3, 5, 7, 8

INTRODUCTION

The Information and Communication Technology (ICT) sector in Canada is a $74 billion per year industry (ICTC, 2015) that contributes to Canada’s growth. The Information and Communications Technology Council released a report in 2016 which stated that 182 000 skilled digital workers will be needed by 2019; however, current domestic and international graduates will not meet this demand (ICTC, 2016). This report includes a national strategy to develop Canada’s ICT talent, and one of its recommendations is to engage elementary and secondary youth in Science, Technology, Engineering, and Math (STEM) and ICT activities.
A main component of ICT is computational thinking, which was defined by Jeannette Wing as "[involving] solving problems, designing systems, and understanding human behaviour, by drawing on the concepts fundamental to computer science" (Wing, 2006, p.33).

Many barriers exist that make it difficult to include computational thinking and programming activities in elementary classrooms, from the absence of a national curriculum to a lack of interest in programming from both students and parents (Wong, Ching, & Huen, 2015). However, a large barrier is the absence of teachers' training and teaching competency in coding and computational thinking (Wong et al., 2015). In Alberta, Canada, a report showed that less than half of Alberta elementary teachers had university education in math and science subjects (Rowell & Ebbers, 2004). Even if students are keen on the subject of computational thinking and a curriculum is put into place, elementary teachers may lack self-efficacy in the subject and struggle to implement computational thinking activities that teach the necessary content without decreasing time spent in other subjects.

This paper proposes a framework that is a modified version of the Conceive-Design-Implement-Operate steps from the CDIO Syllabus (Crawley, Lucas, Malmqvist, & Brodeur, 2011). The framework aims to support teachers in the design and implementation of computational thinking activities for K-6 students. The contributions of this paper are as follows:

- A method for modifying the existing CDIO Syllabus for other subjects
- A modified CDIO framework for teaching computational thinking to K-6 students and teachers
- An example activity created using the new framework, and a walk-through of the designed activity

The rest of this paper is organized into sections. First, background in computational thinking and K-12 CDIO applications is given. Next, the method for modifying the CDIO syllabus is described, as well as how the computational thinking activities may be designed. The new framework is then discussed, and put into context with a worked example of one of the designed activities. Finally, conclusions and future work will be briefly discussed.

BACKGROUND

Computational Thinking

Following Wing's 2006 definition of computational thinking, there have many different definitions of computational thinking over the years. Grover & Pea (2013) state that the following concepts are generally considered a part of computational thinking:

1) Abstractions and pattern generalizations (including models and simulations)
2) Systematic processing of information
3) Symbol systems and representations
4) Algorithmic notions of flow control
5) Structured problem decomposition (modularizing)
6) Iterative, recursive, and parallel thinking
7) Conditional logic
8) Efficiency and performance constraints
9) Debugging and systematic error detection
Beyond the concepts, Brennan and Resnick also identify two other dimensions of computational thinking: computational thinking practices, which are the problem-solving practices that occur in the process of programming; and computational thinking perspectives, which involves the students’ understandings of themselves, their relationships to others, and the technological world around them (Brennan & Resnick, 2012).

Computational thinking has been taught many ways, both in informal learning settings and inside formal education systems. Informally, computational thinking has been taught in after school coding clubs (Kafai, Fields, & Burke, 2008), museums (Horn, Leong, & Block, 2012), and public spaces (Sengupta & Shanahan, 2016). In formal education, computational thinking and programming are often taught at the high school level as an elective, though it is a mandatory subject in some European countries (European Schoolnet, 2015). There is less adoption of computational thinking at the elementary level. It can be seen in European countries including Slovakia, Estonia, and Finland (European Schoolnet, 2015), and especially in England, where the traditional ICT curriculum has been replaced with computer science, information technology, and digital citizenship topics (Berry, 2013). Topics for students of this age include understanding algorithms, writing simple programs, debugging, and understanding how search results are ranked (Berry, 2013). Currently, no such curricula for computational thinking exists nationally in Canada, though some provinces have made steps to include coding in their elementary schools (Province of British Columbia, 2016).

Computational thinking and engineering design are intertwined. Lee et. al. (2011) state that computational thinking has elements of mathematical, engineering, and design thinking, and can also be used to extend those skills. As well, modeling is understood to be a design activity as it involves selecting variables and phenomena, developing a representation, and then testing that representation (Sengupta, Kinnebrew, Basu, Biswas, & Clark, 2013). As CDIO is a design thinking framework, it can be used to teach and extend computational thinking concepts and practices.

**CDIO in K-12 Education**

While the CDIO Syllabus is mainly intended for use in post-secondary engineering programs, it has also been used at the K-12 level. For example, high school students have been involved in CDIO-based robotics projects (Arboleda, Pe, & Casta, n.d.). There are few uses of CDIO at the elementary (K-6) level. An egg-drop challenge was conducted in Sweden to strengthen design, building, and testing skills in 11-year-old students (Traff, Wedel, Gustafsson, & Malmqvist, 2007). Another study involved using the Conceive-Design-Implement-Operate steps to design and implement learning activities about electricity for grade 5 students (Marasco & Behjat, 2013). In that case, the students and teachers themselves were not explicitly using CDIO in those activities.

CDIO has also been used in training teachers. University students studying a BSc in science and technology education used the CDIO approach to balance pedagogy, engineering fundamentals, and teaching practice (Verner, 2015).
METHOD

Creating the Modified CDIO Framework

To begin, an in-depth look at the CDIO Syllabus was needed. The four stages of C-D-I-O are broken down into components, and each of these components contains various considerations. The components are highlighted in Table 1 below.

<table>
<thead>
<tr>
<th>4.3 – Conceiving, Systems and Engineering Management</th>
<th>4.4 - Designing</th>
<th>4.5 - Implementing</th>
<th>4.6 - Operating</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.3.1 – Understanding needs and setting goals</td>
<td>4.4.1 – The Design Process</td>
<td>4.5.1 – Designing a sustainable implementation process</td>
<td>4.6.1 – Designing and optimizing sustainable and safe operations</td>
</tr>
<tr>
<td>4.3.2 – Defining function, concept and architecture</td>
<td>4.4.2 – The design process phrasing and approaches</td>
<td>4.5.2 – Hardware manufacturing process</td>
<td>4.6.2 – Training and operations</td>
</tr>
<tr>
<td>4.3.3 – System engineering, modeling and interfaces</td>
<td>4.4.3 – Utilization of knowledge in design</td>
<td>4.5.3 – Software implementing process</td>
<td>4.6.3 – Supporting the system life cycle</td>
</tr>
<tr>
<td>4.3.4 – Development project management</td>
<td>4.4.4 – Disciplinary design</td>
<td>4.5.4 – Hardwere software integration</td>
<td>4.6.4 – System improvement and evolution</td>
</tr>
<tr>
<td></td>
<td>4.4.5 – Multidisciplinary design</td>
<td>4.5.5 – Test, verification, validation and certification</td>
<td>4.6.5 – Disposal and life-end issues</td>
</tr>
<tr>
<td></td>
<td>4.4.6 – Design for sustainability, safety, aesthetics, operability and other objectives</td>
<td>4.5.6 – Implementation management</td>
<td>4.6.6 – Operations management</td>
</tr>
</tbody>
</table>

Next, a 7-step programming problem-solving approach from Cornell University (Hilton & Bracy, 2015) was mapped to the existing CDIO structure. This process was done in order to see what steps exist in traditional courses which aim to teach programming, a subject that requires computational thinking. Finally, the new framework was built by considering both of the existing frameworks. Items of CDIO that would likely be beyond the scope of an elementary school project (i.e., system engineering, disposal issues, etc.) were removed. As well, components that were not applicable to K-6 computational thinking activities (such as hardware implementation) were also stripped. It is important to note however that these components may still be present in a computational thinking activity, such as using Lego Mindstorms to program a robot. Finally, terminology and language was simplified such that it is understandable and applicable to not only the K-6 teachers, but to their students as well.

Designing the Computational Thinking Activities

Once the new framework was completed, activities were designed which fit into the framework and would be applicable for K-6 teachers and their students. It was important to have activities that used digital technology, as well as those that did not. As well, activities that require the use of digital technology should not use paid software, as that may limit the
ability of teachers to implement that activity in their classrooms. The two non-computer activities are simple and can be done with students of any age; the activities can be completed by pre-reader students. The other two activities use free software, and are a mix of block-based and text-based programming.

Students as young as grade 5 may already be losing interest in science, technology, engineering, and math subjects (Arnot, James, Gray, Rudduck, & Duveen, 1998; Bussiere, Cartwright, & Knighton, 2004). It is important to include opportunities for these students to engage with computational thinking outside of the STEM disciplines. Therefore, it was deemed necessary for these activities to be cross-disciplinary and tie into other school subjects outside of STEM, such as fine arts. This also provides the benefit of teachers being able to teach computational thinking alongside their mandatory curricula.

RESULTS

Modified CDIO Framework

The 7-step approach to solving programming problems from Cornell University was entirely mapped into three CDIO components, as shown in Table 2. It can be seen that this approach is entirely encapsulated in the CDIO Design step. Therefore, extra care should be taken in designing activities to ensure that they cover each of the Conceive, Design, Implement, and Operate steps.

<table>
<thead>
<tr>
<th>CDIO Step</th>
<th>4.4.4 – disciplinary design</th>
<th>4.5.3 – software implementation process</th>
<th>4.5.5 – test, verification, validation and certification</th>
</tr>
</thead>
</table>
| Cornell 7-step approach | 1. work example by hand  
  • make sure the problem is fully specified  
  • may require domain knowledge | 5. translate to code | 6. run test cases  
  • to uncover errors in the algorithm or its implementation  
  7. debug failed test cases  
  • may need to go back and redesign the algorithm or check code translation/implementation |
| 2. write down what you did | 3. find patterns  
  • generalize your steps | | |
| 4. check by hand | test your algorithm to ensure your logic is sound | | |

Table 3 contains two columns: the first column includes the original CDIO framework. The breakdown for each component is not included due to space requirements, but can be found in the CDIO Syllabus. The second column is the proposed adapted CDIO framework for use in teacher professional development in computational thinking.
<table>
<thead>
<tr>
<th>4.4 - DESIGNING</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.4.1 - The design process</td>
</tr>
<tr>
<td>4.4.2 - The design process specifications and approaches</td>
</tr>
<tr>
<td>4.4.3 - The design process requirements for each element of the component derived from system level goals and needs</td>
</tr>
<tr>
<td>4.4.4 - The design process management</td>
</tr>
<tr>
<td>Table 3. Proposed modified CDIO framework for K-6 computational thinking</td>
</tr>
<tr>
<td>4.6 OPERATING</td>
</tr>
<tr>
<td>---------------</td>
</tr>
<tr>
<td>System Issues</td>
</tr>
<tr>
<td>System Evolution</td>
</tr>
<tr>
<td>System Improvement and Cycle</td>
</tr>
<tr>
<td>Training to use final product</td>
</tr>
<tr>
<td>Sustainable and safe operations</td>
</tr>
<tr>
<td>Consider process improvements: was there a better way to do the programming?</td>
</tr>
<tr>
<td>Does it solve the problem?</td>
</tr>
<tr>
<td>Does it work according to the design?</td>
</tr>
<tr>
<td>The system build</td>
</tr>
<tr>
<td>The low-level design (coding) with the programming languages and paradigms</td>
</tr>
<tr>
<td>The integration (data in/out, control flow, data flow)</td>
</tr>
<tr>
<td>The breakdown of high-level components into module designs (including algorithms and code readability)</td>
</tr>
<tr>
<td>Other disciplines, safety, security, operability and sustainability between disciplines</td>
</tr>
<tr>
<td>Modeling the high-level program (e.g., a program, step-by-step through the program)</td>
</tr>
<tr>
<td>Consider the applicability of the programming language</td>
</tr>
<tr>
<td>Consider the applicability of the programming language</td>
</tr>
<tr>
<td>Using prior work (reusing code)</td>
</tr>
</tbody>
</table>
Example Activity and Framework Mapping

Of the four activities developed using the framework, an activity titled *Scratch Stories* will be discussed in detail. It will highlight the role the modified CDIO framework played in its creation and the framing of guiding questions and steps to help teachers work through the C-D-I-O steps for the activity. Those questions are written in such a way that they are appropriate for both the teachers and their students.

*Scratch Stories* uses MIT’s Scratch (http://scratch.mit.edu), which is a block-based program that is said to be “low floor, high ceiling” (Papert, 1980). This means that it takes very little knowledge to write a basic program in Scratch, but at the same time it is possible to create very advanced projects. Scratch was chosen as it is well-known in the K-12 environment, is free, and can be completed on a browser rather than requiring downloaded software. Visual and block-based programming languages are preferred for K-6 students as they are not syntax-dependent and often sound like spoken English.

*Scratch Stories* is a cross-curricular activity which ties together the computational thinking concepts with English Language Arts requirements of story writing. Teachers will use MIT’s Scratch program to write a story with a beginning, middle, and end. This story must have at least two characters. This provides a strong basis for all four C-D-I-O steps; teachers must *conceive* what their story is about before *designing* the scenes, characters, and actions in detail. They must then *implement* the story using Scratch. Finally, they will *operate* their own story and the stories of other teachers and students, taking care to ensure that it can reset itself, and thinking of ways it can be improved.

This activity is intended to be the third activity in a professional development workshop about computational thinking for K-6 teachers. Previous activities will have introduced computational thinking and its concepts such as sequences, loops, parallelism, events, conditionals, operators, and data (Brennan & Resnick, 2012). These concepts will have also been explained in the context of real-life algorithms. For example, recipes may have sequences (what you have to do in what order), parallelism (cutting a vegetable while boiling the water), and events (putting it in the oven once it reaches a certain temperature). Teachers will also have put these concepts into practice while learning about the two non-computer activities that require modelling tasks, such as navigating a maze or doing a dance as a robot. *Scratch Stories* makes the jump to digital devices and block-based programming, where teachers will still be using the concepts they are familiar with, but in an environment that may feel closer to their prior perceptions of programming.

Before beginning the activity, teachers are given a walkthrough of Scratch using a narrated screen capture. It covers the basics of Scratch and three examples of increasing difficulty that highlight different aspects of Scratch in relation to the computational thinking concepts learned previously.

The following sections will detail the researcher’s experience as she works through each of the C-D-I-O steps for *Scratch Stories*. 

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*Proceedings of the 13th International CDIO Conference, University of Calgary, Calgary, Canada, June 18-22, 2017.*
Conceive

The Conceive step is essentially the storyboarding process. It asks questions such as: what will the story be about? What do the characters need to do? It also asked participants to think about how they should be graded (meeting requirements? enjoyment?) and what time limit they have for completing the project.

The researcher has decided that her story will be about two aliens who have built a spaceship to come to Earth. She has informed this decision by noting the various space-related sprites and backgrounds, as seen in Figure 1 below. She will need two different alien characters, a spaceship, and some kind of space background. The characters will need to be able to talk, move, and disappear so that it looks like they are in the spaceship. The spaceship will also have to move. There is no time limit for her project, and she will consider it a success if she creates a story that takes at least 30 seconds to run and is enjoyable.

![Sprite Library](image1)

![Backdrop Library](image2)

**Figure 1.** Space sprites and backdrops in Scratch

Design

Next, the researcher begins designing her story by considering the requirements of each scene. She can then break down those scenes into actions to be coded separately. Different actions and scenes are based on the available Scratch blocks. She does not have any previous code from a project to reuse, though she could check Scratch’s online database of projects to see what others have done. In order to figure out the scenes, she will need to model each scene from the point of view of each character, to break down what each character will need to do and say. Finally, she should consider how to reinitialize the scenes such that the story can be replayed over and over again easily.
Scene 1 (Beginning): Tera finishes working on her spaceship and announces it is done (speaking)!

Scene 2 (Middle): Pico walks over (moving) to check out Tera’s good work (speaking), and tearfully says goodbye to his friend (more speaking).

Scene 3 (Middle): Tera gets into the spaceship (turns invisible using the ‘show’ block) and flies away (spaceship must move).

Scene 4 (End): Spaceship is seen moving in the stars towards Earth (will need a backdrop change, spaceship moving, and the Earth sprite to appear).

Implement

The Implement step is where all of the coding occurs. It should be done scene by scene in steps, coded separately, and then brought together at the end. Scene changes, sprite costumes, and timing should all be considered here to make the final story flow nicely. Again, resetting the story must be considered, especially since the researcher should be testing as she goes to ensure everything is working properly.

Various challenges were encountered while writing the code, such as Tera answering before Pico had even asked a question, Pico walking the wrong way, and trying to figure out exactly when the spaceship should start moving. Tera originally wasn’t facing Pico during the conversation, which required a costume change so that she could look in the correct direction. It was also difficult to make Pico disappear and the Earth appear when the background changes to "stars". Rather than requiring on timing, a conditional statement was used that made the code more complicated. It seemed to work well for Pico disappearing, but the Earth was appearing too early in the story. In the end, a workaround was used as it was decided that it was a good thing for the Earth to be seen in the sky on the distant planet anyways. Finally, some text was created that would show up when the script was over, telling the user how to restart the story.

Figure 2 below shows the code written for Tera in the story, with the different scenes highlighted. The full project and code for all characters can be found at: https://scratch.mit.edu/projects/140885571/
Operate

Finally, the researcher should let others know how to operate the story. In this case, clicking the green flag at the beginning starts the story, and she has included some text that pops up at the end to tell users they can restart the story by clicking on the green flag again. She can consider how to improve or extend the story, such as having a scene with Tera landing on Earth and meeting humans for the first time. Finally, as Scratch projects can be posted online, she should consider digital citizenship and safety. She has not included any personal information in the story, and is using the internet in a safe and responsible manner. Her story has met her requirements as set in the Conceive step; it is enjoyable and takes 38 seconds to run.

CONCLUSION

In conclusion, the Conceive-Design-Implement-Operate steps can be modified such that they are applicable to an audience outside of post-secondary engineering education, including K-6 teachers and their students. It can also be tailored towards a specific subject, such as computational thinking, to create a framework that can then be used in teacher professional development. The new framework can be used to create activities that teach computational thinking concepts along with engineering design thinking. These activities can then be used in a professional development workshop for teachers.
Future work will see the implementation of this framework and activities within a professional development context. Quantitative data will be collected using surveys to determine changes in teachers’ perceptions of computational thinking and their self-efficacy regarding the subject. As well, the modified CDIO framework will be used as a basis for directed content analysis for teachers’ written reflections about their experience in the professional development workshop.

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**BIOGRAPHICAL INFORMATION**

**Stephanie Hladik**, is a M.Sc student in Electrical Engineering at the University of Calgary. Her research focuses on the inclusion of engineering education in K-12 curricula. In particular, she is interested in the ways that computational thinking and programming can be taught at the K-6 level, considering both the students and their teachers. Outside of her research, Stephanie is involved in many outreach programs to get K-12 students excited about STEM and alongside her colleagues has recently founded a company, LATTICE Development Inc., to bring research-tested cross-curricular STEM activities to schools.

**Laleh Behjat, PhD, PEng**, is an associate professor in the Department of Electrical and Computer Engineering at the University of Calgary. Her research interests include developing software for the automation of the design of computer hardware. She has won several awards for her research in international contests and forums. Dr. Behjat has a passion for increasing the status of women in science, technology, engineering and mathematics (STEM) and has an active research in the area of Engineering Education. Dr. Behjat was the recipient of the 2015 Association of Professional Engineers and Geoscientists of Alberta (APEGA) Women in Engineering Champion Award.

**Anders Nygren**, holds an MSc (Electrical Engineering) from the Royal Institute of Technology, Stockholm, Sweden; an MSEE from the University of Houston, Texas; and a PhD from Rice University, Houston, Texas. Prior to joining the Schulich School of Engineering in 2004, he completed postdoctoral training in Physiology & Biophysics at the University of Calgary. Dr. Nygren has taught courses in Biomedical Engineering and in the Common Core Engineering program at the Schulich School of Engineering.

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INNOVATIVE LEARNING SPACES FOR EXPERIENTIAL LEARNING: UNDERGROUND MINES

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ABSTRACT

Underground Mining is characterized by a high degree of complexity and singularity due to specific deposit conditions and complex interactions with the environment. To gain a deep understanding of underground processes and its influencing factors traditional abstract teaching approaches mainly do not cover these complexities in sufficient detail while at the same time students are lacking of underground experiences and knowledge. To connect the students as early as possible with potential future working environments the understanding of relevant methods and processes could be facilitated by hands-on-teaching situations and/or in authentic learning spaces.

Facing these challenges the objective is to design, select and integrate authentic learning spaces into underground mining engineering courses and to encourage experiential learning. For a successful course implementation the learning spaces need to be aligned to the intended learning objectives and respective teaching and learning methods.

Therefore, different authentic learning spaces for fostering experiential learning were consequently developed and successfully implemented into existing courses of B.Sc. as well as M.Sc. - Program at the Institute of Mining at Clausthal University of Technology in recent years. Places for these teaching-and-learning activities is for example a research and teaching mine, which was established at the former ore mine and nowadays World Heritage Site Rammelsberg in close distance to the university. Furthermore cooperation with mining companies, manufacturers and other operators of underground facilities were assembled to design learning spaces fitting to the course content, learning situation and lecturer philosophy. In addition the spatial situation at the Institute was revised and working spaces are set up as a flexible learning environment.

The paper will give an overview of the realization of the CDIO Standard 6 in the framework of Underground Mining Education by presenting examples of innovative authentic learning spaces and their implementation into Mining Engineering courses at Clausthal University of Technology.
INTRODUCTION

Underground Mining is characterized by a high degree of complexity and singularity due to specific deposit conditions and complex interactions with the environment. The working environment is mainly unique, only partly known and difficult to understand. The influencing factors are diverse and connected to cluster of origin as well as the processes and approaches for mine design and operation are complicated. The connection of aspects makes it difficult for the students who are lacking of underground experiences and knowledge at the same time for understanding and following the course content. Hence traditional teaching approaches are less appropriate to cover and communicate the described complexities. Therefore it is a challenge for lecturers in this field to guide students to gain a deep understanding of underground processes and its influencing factors. Innovation is needed.

Our approach is to familiarize students as soon as possible with the future working environment and potential working situations. Experiential learning is fostered by hands-on-teaching situation. Locating them in authentic learning spaces completes the approach.

The objective is to combine experiential learning with authentic learning spaces to foster a deeper and holistic understanding of the complex area of safe, efficient and sustainable underground production of raw materials. Therefore it is necessary to design, select and integrate authentic learning spaces into underground mining engineering courses and to encourage experiential learning.

For achieving these goals different authentic learning spaces were consequently developed and implemented into existing lectures of B.Sc. as well as the M.Sc.-Course at the Institute of Mining of Clausthal University of Technology (CUT). The papers will give two examples for the implementation focusing on the “Learning Lab” and the “Research and Teaching Mine Rammelsberg”.

SPACES FOR EXPERIENTIAL LEARNING / CDIO STANDARD 6

Experiential Learning as introduced by (Kolb & Fry, 1974) analyzes the general natural learning approach of humans to transfer it to the educational background. The experiential learning model is based on four stages, which form a cycle: a concrete experience is followed by observations and reflections in the second stage, where data about the experience are collected by reflecting on the experience. In the third stage the data are analyzed during the formation of abstract concepts and generalization. The concept developed is tested in the fourth stage with implementation and application to a new situation. Individual learning styles are established by the emphasis set and methodology chosen in the different stages. Hence Implementing Experiential Learning means to consider the
different learning stages and to offer support at the different stages by designing of tailor-
specific course content and environment.

Each learning experience takes place in a multilayered environment. (Bronfenbrenner, 1977;  
Bronfenbrenner, 1979) defines four systems as levels for the learning Space: Microsystem,  
Mesosystem, Macrosystem and Exosystem. The immediate setting which can be a  
classroom is described by the microsystem. The Mesosystem is represented by the closer  
environment of the learners for example his/her family and life situation. The Exosystem  
comprises the structures which influences the person’s environment. Examples are formal  
and informal social structures. The Macrosystem is influenced by the institution and society  
with their structure, values and culture. As a teacher we can reasonably change the  
Microsystem by adjusting the style and environment of our lecture. Changes in the other  
systems can be just partly initiated by teachers. Therefore the paper focuses on the  
Microsystem with a particular focus on the spatial design.

The sixth Standard of the CDIO Initiative also deals with the physical design of the learning  
Environment in CDIO based Engineering Education. The Standard is formulated as:

“Engineering workspaces and laboratories that support and encourage hands-
on learning of product, process, and system building, disciplinary knowledge  
and social learning” (CDIO Initiative, 2010)

Hands-on-Learning focuses on the real experience as the event, which starts the learning  
cycle. The present work also implements the sixth Standard of CDIO.

Besides the chaperonage, appropriate guidance and partly instruction in the stages  
observation/reflection, concept design and testing emphasis is particularly on the use of  
Underground Spaces to provide conducive experience. Two of these learning spaces will be  
described in the following section.

UNDERGROUND LEARNING SPACES FOR MINING ENGINEERING EDUCATION AT  
CLAUSTHAL UNIVERSITY OF TECHNOLOGY

Today’s Clausthal University of Technology (CUT) was founded in 1775 as a mining  
academy. During its history, the Royal School of Mines (1864) broadened its focus and  
covers today in research and study programs the whole range from natural sciences and raw  
materials to material sciences, over mechanical and Process Engineering to Economics,  
Computer science and advanced Electronic Waste Recycling. CUT main research areas are  
Sustainable Energy Systems, Raw Material Supply and Efficiency, Materials Science and  
Processes, Cyber-Physical Systems and Simulation - more than 50% of the professorate are  
acting in Raw Materials related research areas, coordinated in Clusters for fostering  
interdisciplinary research. The University runs several students laboratories and a Research  
and Teaching Mine in cooperation with the World Cultural Heritage Rammelsberg, a former  
ore mine with more than 1000 years of production and supports a well-established network to  
regional and nationwide industrial partners. Good teaching with the integration of  
competence-oriented, students-centered innovative teaching and learning approaches is  
import for CUT. Therefore the Centre for Higher Education offers a Professional Certificate in  
Teaching and Learning in Higher Education as well as a variety of different courses in Higher
education and personal coaching. CUT is a partner in the project “European Initiative on CDIO in Raw Material Programmes” (Edelbro et al., 2017) with the focus on Faculty Development and hence participation in CDIO- courses as well as design and enhancements of student workspaces, labs and active and experimental learning. Besides developing innovative methods for the 21st century mine of the future, the aim of the Institute of Mining is to educate engineers who are able to develop and apply up-to-date advanced mining technologies and to face the challenges of today’s and tomorrow’s global mining industry.

For coping with the challenges of the Mine-of-the-Future, future Mining Engineers need besides a deep understanding of fundamentals of engineering and geosciences and the ability to complex systemic thinking well trained competences in the sense of “T-shaped” professionals. Therefore traditional teaching methods focusing on broad transfer of knowledge need to be complemented with innovative teaching and learning approaches. Nevertheless experience made in the tradition of teaching are still considered. A main issue is the involvement of hands-on elements. This papers presents two spaces and their usage mainly in the lecture “Mine Ventilation and Climatization”, which is part of the Bachelor Course B.Sc. Energy and Raw Materials. The general teaching concept in the field of Ventilation and Climatization, which is underlying this lecture is described in (Clausen, 2015). The „Learning Lab“ provides in a two room situation the possibility to go through all steps of product design. In the respective lecture the situated Ventilation Lab is used. The “Rammelsberg Mine” offers a plenty of working spaces in Underground, which are exemplary presented. On the one hand the lab provides a self-learning environment for student research. On the other hand the Rammelsberg Mine represents a mining environment, where students can deal with realistic case studies and szenarios.

Learning Lab

The idea of the “Learning Lab” is to provide appropriate rooms for groups as well as for individual work, which can be used for all lectures during the contact hours or self-learning time. The principle enables teachers as well as learners to use the room in a diverse and modularized manner, which can be adapted easily to different requirements. The development of the room concept started in 2013 with the provision of the room and is still ongoing. Meanwhile different teaching/learning concepts were realized in the room. A considerable change was caused by the modernization of the building and the associated move to new rooms. Taking this change as an opportunity a room concept was developed which is inspired by different presentations at the 12th International CDIO Conference in Turku. The concept is not fully implemented due to ongoing construction works. Figure 1 shows the actual setting in the experiential part of the Learning Lab.
The objective of the concept is to design a flexible working space which enables students and teachers to establish different flexible teaching and learning settings while minimizing space constraints. Therefore flexible furniture is installed. In the group working room the table as well as the chairs are adjustable in height. For presentation and discussion purposes a central monitor as well as whiteboards and other paper based moderators materials can be used. The experiential room shown in an earlier development stage in Figure 1 is furnished with foldable table and stackable chairs. Therefore different settings can be realized by rearranging these. Different models of mining methods (e.g. hanging from the ceiling), ventilation methods and shaft support are located at the Lab.

The central part of the learning lab with reference to the education in the field of Mine Ventilation is the test stand, which is developed internally at the department. Within tutorials and assignments students develop their understanding of fluid dynamics and its relevance to mine ventilation by using and modifying the test stand. Different settings can be assembled, measured and analyzed with minor support of a student assistant. The room provides the possibility for further discussions so that the student can stay in the room based on their individual pace and learning progree.

In both rooms storage compartments are installed for personal, group and teaching items. The access is realized by a chip-based lock system which allows a flexible entrance for students. The learning lab represents a learning space directly at the facilities of the university, which can be used flexible by students and teachers.

**Rammelsberg Mine**

The Rammelsberg Mine is a former ore mine situated at the northern edge of the Hercynian mountains in the city of Goslar. The mine production was documented over 1,000 years until it was terminated in 1988. Meanwhile more than 30 million tons of silver, copper and lead ore were extracted. After closure the mine was transformed into a Museum, which welcomes more than 100,000 visitors annually. In 1992 the Rammelsberg became with the historic city of Goslar a UNESCO World Heritage site, which was expanded in 2010 by including the Upper Harz Water Management system.
After establishing an official partnership in 2010 between CUT and the World Heritage Site Rammelsberg the former ore mine became the teaching and research mine of the University at the 16th of January 2013. The partnership was shaped by research projects underground, scientific conferences on montane history and mainly on lectures conducted at the Rammelsberg Mine. The alliance combines the traditional mine site with the innovation of research and education at CUT. The variety of possible uses exceeds the framework of this paper. Therefore typical examples are shown below.

The Rammelsberg Mine offers plenty of rooms, which can be used in a variety of different settings. Besides the surface installation with seminar rooms (e.g. for safety instructions) mostly all open areas in underground can be used. Restrictions are caused by areas with instable conditions and the flooding process. Due to flooding of the lower levels after the termination of production cavities are only usable in the higher area above the “Rathstiefsten Stollen” which is the level of 293 m. Underground learning location can be equipped with chairs and benches as well as with presentation equipment, power supply is available.

Figure 2 shows a common learning situation located in Underground. The main advantage of locating this kind of learning activities underground is the vicinity to the mining environment where effects can be shown and measurements can be undertaken. Additionally the students are more concentrated due to the insufficient mobile network. At the Rammelsberg Mine rooms for different group sizes up to 50 people are available. So the learning space can be adjusted to the situation. These areas are appropriate for group based learning as well as for example for preparing measuring campaigns.

Figure 2. Learning in Underground

The design, conduct and evaluation of a Ventilation survey is an important and major tasks of Mining Engineers working in the field of Ventilation. The students are learning while working on specific tasks how to plan, conduct and analyze a mine ventilation network. They work individually or in a group as shown in Figure 3. Besides the direct tasks the students foster
their skills in project management, organisation and documentation and need to show social and self-competences.

Figure 3. Ventilation survey, individually (left side) and in a group (right side)

By the selection of the settings different levels of difficulty can be realized. Figure 4 shows the comparison of two situations. The left one can be used for the introduction on a basic level.

Figure 4. Different settings, simple (left side), more complex (right side)

The elements are clear and the drift has no curve. The right situation is more challenging: besides the duct different types of support and intersection of drifts must be considered. Students develop by understanding the simple setting according to the Experiential Learning Approach a procedure for measuring which can be tested and refined by application in more complex situation. For being successful in underground mining operations it is important to get a quick and thorough overview of the environment and the influencing factors and then having the ability and “toolbox” to adapt known procedures to the specific conditions.

Another situation is shown in Figure 5 where old equipment nowadays used in an exhibition, and technical information presented as a poster are combined. Using the technical exhibition area, where the drilling and blasting cycle for road development in ore Mining is presented, students for example have the task to calculate the needed amount of fresh air. Therefore they need to analyze and understand the process, filter the given – partly unnecessary - data to get the relevant information and to use appropriate engineering tools for finding the solution. A following task could be the ventilation design for the exhibition area which is directly comparable to an underground mining section. In summary students tend to believe “understanding” simply is the ability to reproduce knowledge. But reality comes with unexpected challenges. Conducting our ventilation tutorials at the Rammelsberg Mine, they are challenged with tasks and problems that ventilation engineers are facing every day. Questions arise and students start approaching the problems from an all new position, consolidating their knowledge. Most of the students say, they would highly appreciate the practical tutorials as they were a good complement to the lecture. In addition (Clausen, 2015) observed a general positive relationship between a combined teaching and learning approach using lectures in class, hands-on learning in lab and learning in an authentic learning venue on the professional performance, acquisition of competences and student`s motivation.

The following exemplary feedback from students show that they see a direct relationship between the integration of authentic and innovative learning spaces and their individual learning success:

- "In opposite to many other lectures, the mine ventilation course allowed us to demonstrate our theoretical knowledge from the lectures in a practical mine ventilation surveying situation. However, we did not only apply our knowledge, but we were also facing new, unexpected problems that had to be solved on the spot. Conducted like in a
real engineer’s life situation, the tutorials at Rammelsberg prepared us best for our future
every day job in a mine.”
• “I highly appreciated the practical orientation of Mine Ventilation I. Surveying at
Rammelsberg Mine helped me to gain a feeling and practical understanding for the
measurements. Leaving the lecture hall and applying my knowledge in a real mine
surrounding enhanced my comprehension of the course’s content as well as my interest
in the subject itself.”

PERSPECTIVES

This paper presents an excerpt of innovative learning spaces, one in underground.
Additionally the integration of field trips, underground project work and other authentic and
realistic learning / teaching activities lead our students to individual learning experiences
which foster a deeper learning and understanding while enhancing at the same time
additional relevant key competences.

Involving the feedback and evaluation of students as well as the personal experience and
latest scientific findings concepts for experiential learning and appropriate learning spaces
and their implementation to the study courses will be further developed and enhanced. The
cooperation with already existing and new partners such as the CDIO Initiative opens doors
to new ideas and challenges. The primarily goal will always be to prepare and enable our
students best to their professional and social life.

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Materials. The project is presented in (Edelbro et al., 2017).

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INTEGRATING CDIO PHILOSOPHY INTO MANUFACTURING ENGINEERING CAPSTONE PROJECTS

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ABSTRACT

Groover defines automation as the technology by which a process or procedure is accomplished without human assistance (Groover 2008). Automation continues to filter through all levels of modern manufacturing and with the advent of Industry 4.0 will continue to push the boundaries of manufacturing forward. Items such as robotic control, integration of vision systems, RFID and traceability are paramount to successful manufacturing facilities worldwide. Because of this level of automation in modern manufacturing it is paramount that the manufacturing engineering graduate has the skills required by industry to design, develop and evaluate solutions to industrial automation issues. Graduates typically work as part of an interdisciplinary team in close collaboration with the other members. It is desirable to develop a suitable skillset in the graduates to facilitate this type of activity.

Strobel & Barneveld indicate that “PBL is significantly more effective than traditional instruction to train competent and skilled practitioners and to promote long-term retention of knowledge and skills” (Strobel & Barneveld 2009). With this in mind, the way in which automation has been integrated into the capstone projects of a Manufacturing Engineering programme will be presented in this paper.

The integration and assessment/feedback mechanisms have been designed and constructed to reflect a CDIO learning approach, where students are assigned a typical industrial problem and asked to conceive solutions, evaluate the best alternative, optimise the design, implement and operate the solution. Students are given feedback on Design phase, Implementation and Operation of the project, with all stages contributing to the final grade in the module. Skills such as collaboration, proactive solving and subject specific knowledge are also assessed.

This paper will outline both qualitative and quantitative feedback from the students involved, outlined the project being undertaken and detail the assessment and feedback mechanisms used.

Additionally, the paper will illustrate how a CDIO approach with a specific focus on industrial problems encourages student engagement but more importantly prepares students for issues they will experience in their role as engineers in an industrial environment.
KEYWORDS

Capstone Project, Assessment, Feedback, Standard 5, 7 & 8

INTRODUCTION

Engineering students, on graduation, will enter the field of professional practice and will be expected to provide added value in their field of engineering. It is the role of the third level institution to ensure that these graduates have the necessary skills and competencies to add this value. Through the CDIO approach students are immersed in both the technical and theoretical competencies which helps ensure that engineering graduates have skills such as communication, collaboration and problem solving. A key aspect to any undergraduate programme is the capstone project, traditionally though not always, an individual project which requires detailed planning, coordination, research and integration to develop a solution to a predefined problem.

As with all projects there are a number of key stakeholders who need to be satisfied through the project:

a. The student: Who will require mentoring/supervision throughout the project to ensure project approach is valid, analysis is complete and overall project is of the standard required;

b. Project Supervisor: Who will/should provide structured feedback throughout the project to help ensure that the deliverables and expectations are satisfied;

c. Industry: The project should reflect the content of the student’s undergraduate programme and help ensure the student is ready to meet the challenges of industry expectations;

d. Accreditation Bodies: A key fundamental of accreditation is the ability of the institution to produce student work that reflects the undergraduate programme; the capstone project helps fulfil this requirement. For the purpose of this paper the accreditation requirements are those of Engineers Ireland.

It is apparent that a capstone project has a number of stakeholders, each with different expectations, each with different roles and requirements. This paper presents a format which structures the Design and Manufacture Engineering capstone project in a manner which balances the requirements of the identified stakeholders. To achieve this balance, institutions need to balance three significant pillars within the capstone project; Project Feedback, Project Structure and Project Assessment.

Project feedback

Clynes and Faftery suggest that feedback is “an interactive process which aims to provide learners with insight into their performance” (Clynes & Faftery, 2008). The important aspect to note here is that it is an interactive process; students should be involved in the process, should have the ability to digest the feedback, question it and learn from it. Feedback should be provided in a manner which is constructive and meaningful and which promotes successful teaching. (Ovando, 1994).
By providing feedback in a structured and meaningful manner, students have the ability to learn from their mistakes, take suggestions on board and improve their work. However, if the feedback provided is merely prescriptive in nature the students’ ability to learn is diminished, therefore care is required when providing feedback to ensure that errors are illustrated but students are encouraged to work through to solutions independently.

In general feedback is universally encouraged. Feedback is essential for students’ growth, provides direction and helps to boost confidence, increase motivation and self-esteem (Clynes & Faftery). The format of this feedback is important – Macelllan (2001) suggested that improvement in learning occurs when students perceive feedback as enabling learning, and not just as a judgement on their level of achievement, while Wojtas (1998) claims that many students improve their work once they understand the purpose of feedback and assessment criteria. A study performed by Weaver illustrated that “An overwhelming majority of students from both Business and Design agreed with the statements ‘constructive criticism is needed to know how to improve’ and ‘feedback is helpful to explain gaps in knowledge and understanding’”. (Weaver 2006)

Feedback and Motivation

Gorham and Millette (1997) found that student motivation was mainly intrinsic and that the way the learning experience was structured has a large part to play in how this motivation is sustained. Course design is therefore as important, if not more so, than teacher behaviour in this regard. They also highlight the link between effective feedback and motivation. Canty & Seery (2011) showed the value of peer feedback in undergraduate work.

Hattie and Tymerly (2007) presented a compelling argument in favour of implementing structured feedback at a number of levels - based on a meta-analysis of 196 studies and 6,972 effect sizes, they found that the average effect size when providing structured feedback was 0.79. To place this average of 0.79 into perspective, it fell in the top 5 to 10 highest influences on achievement, along with direct instruction (0.93). Hattie and Tymerly describe a model of feedback based on the idea of addressing the discrepancy between the current state of a learner’s knowledge and that desired. They suggest that feedback operates on four levels - Task, Process, Self-Regulation and Self, as shown below in Figure 1. Feedback can be captured by answering three broad questions: “Where am I going?”; “How am I going?” & “Where to next?”
The feedback can be addressed by providing information on these three questions to the learner:

1. Where am I going? – In other words, how does the feedback clarify what the goals of the work are? (E.g. “..... The type or level of performance to be attained so that (the learners) can direct and evaluate their actions and efforts accordingly. Feedback allows them to set reasonable goals and track their performance in relation to their goals so that adjustments in effort, direction and even strategy can be made as needed....”)

2. How am I going? The second question is more related to progress feedback. This entails feedback (about past, present or how to progress) relative to the starting or finishing point and is often expressed in relation to some expected standard, to prior performance, and/or to success or failure on a specific part of the task. Feedback information about progress, about personal best performance and comparative effects to other students can be most salient to this second question.

3. Where to next? The third question is more consequential. Such feedback can assist in choosing the next most appropriate challenges, more self-regulation over the learning process, greater fluency and automaticity, different strategies and processes to work on the tasks, deeper understanding, and more information about what is and what is not understood. (Hattie & Tymperly, 2007)

Therefore, it is clear that structured feedback is an essential component in maintaining student engagement and motivation in a course of study. This is particularly so in the case of a capstone project where the students work is largely self-directed. Conversely, non-structured feedback is largely ineffective as shown previously by Clynes and Fahtery (2008).
Project Structure

The structure of a capstone project requires skills and knowledge acquired through research and study to be applied back to the problem; students evaluate the effectiveness of their research activities and the application of their research results to the problem at hand, while integrating their new learning with their existing knowledge (Dunlap, 2005). Traditionally, capstone projects in the undergraduate programmes are performed individually with a predefined subject area/and project brief. Students then define and scope the project, formulate a design solution, evaluate this solution and communicate findings through a final report and presentation. This paper will examine how best to implement a CDIO framework on the capstone project to ensure that students develop Problem Based Learning (PBL) skills such as critical evaluation, communication, change anticipation and the ability to make decisions in unfamiliar areas (Dunlap, 2005).

Project Assessment

The goal of assessment is to measure the acquisition of higher-order thinking processes and competencies as well as factual knowledge and basic skills. The function of the assessment should not just be summative but should serve a formative goal of promoting and enhancing student learning (Gulikers et al, 2004).

When considering assessment, two aspects are important to consider, i) construct validity, ii) consequential validity. Construct validity refers to whether the assessment technique measures what it is supposed to measure, while consequential validity describes the intended and unintended effects of assessment on instruction or teaching (Gulikers et al, 2004).

As outlined earlier, the capstone project is the culmination of a number of years of undergraduate study, it requires a detailed assessment method which will reflect on the skills developed by the student. The assessment method should provide for a number of project stage gates to facilitate feedback to the student.

The following sections outline a potential CDIO capstone project structure to be used with a Design and Manufacturing Engineering undergraduate class.

Aim

The aim of this paper is to develop a capstone project format which uses the CDIO philosophy and which satisfies student learning outcomes, University and industry graduate attribute requirements and accreditation body requirements. In order to determine the optimum approach, following three components of the Capstone Project are examined:

- Project Structure and how well it currently aligns with the CDIO syllabus and desirable graduate attributes.
- Current feedback mechanisms
- Alignment of the current project with the CDIO syllabus

CAPSTONE PROJECT STRUCTURE

Current Format

The current capstone project format is as follows (see Table 1): students are presented with a list of possible projects, from which the student selects a project and relevant academic supervisor. The academic year in the Academic institution is split into 2 semesters, Autumn and Spring. Each semester is 15 weeks in length.

In the autumn semester students are required to commence the project and have an agreed Final Year Project (FYP) plan by Week 6 of Semester 1. Students submit an interim report in Week 8 of Semester 1, which outlines title, project justification and objectives; it should contain detailed working drawings, material requirements and costings.

Students are required to then give an oral presentation in Week 10 of Semester 1, outlining progress to date, obstacles, significant progress and detailed work plan for project. Work on the project continues until Week 8 of semester 2 at which stage the student presents a written report detailing the work undertaken, literature, methodology, results and discussion. The final report is examined in a viva voce format with a second reader who acts as moderator. Throughout the project students are required to keep a log of all project activity which is reviewed by the supervisor; this illustrates progress of student work and ensures that work is spread evenly across the duration of the project as shown in Table 1.

Table 1. Roadmap and Deadlines for Final Year Project

<table>
<thead>
<tr>
<th>Year 3 Semester 2 Weeks 6-9</th>
<th>Year 3 Semester 2 Weeks 9-12</th>
<th>Year 4 Semester 1 Week 6</th>
<th>Year 4 Semester 1 Week 8</th>
<th>Year 4 Semester 1 Week 9 &amp; 10</th>
<th>Year 4 Semester 2 Week 8</th>
<th>Year 4 Semester 2 Week 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select number of possible project titles</td>
<td>Students advised of allocation</td>
<td>Approval of FYP planning by supervisor</td>
<td>Submission of interim report (Supervisor Feedback)</td>
<td>Interim Oral Presentation (Supervisor Feedback)</td>
<td>Submission of FYP report</td>
<td>Viva Voce exam and poster presentation</td>
</tr>
</tbody>
</table>

An analysis of the current approach indicates that there are a number of areas which could be improved, as mentioned in the introduction section, structured feedback to students is a fundamental learning experience and as such this should be incorporated into the overall FYP assessment structure. A detailed assessment rubric which clearly outlines assessment techniques and justification would help provide justification when discussing assessment with accreditation bodies.

The introduction section of the paper outlined the different stakeholders concerned in the capstone project, Table 2 outlines how these stakeholder requirements interact and how they are currently assessed. In this context, the desired student attributes promoted by the University are relevant and are shown in column 1 of Table 2.
Table 2. Stakeholder Evaluation

<table>
<thead>
<tr>
<th>Graduate Attributes</th>
<th>Accreditation Body Requirements</th>
<th>Relevant CDIO LOs</th>
<th>Current Assessment Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject specific Knowledge</td>
<td>The ability to contribute to the design of components, systems and processes to meet specified needs.</td>
<td>Standard 8</td>
<td>Report</td>
</tr>
<tr>
<td>Pro-activeness</td>
<td>The ability to identify, formulate and solve broadly-defined problems in engineering technology.</td>
<td>Standard 8</td>
<td>Report</td>
</tr>
<tr>
<td>Collaboration</td>
<td>The ability to work effectively as an individual, in teams and in multidisciplinary settings together with the capacity to undertake lifelong learning.</td>
<td>Standard 2</td>
<td>Not Directly Assessed</td>
</tr>
<tr>
<td>Articulate</td>
<td>The ability to communicate effectively on broadly-defined engineering activities with the engineering community and with society at large.</td>
<td>Standard 5</td>
<td>Presentation</td>
</tr>
</tbody>
</table>

As can be seen from Table 2 there are a number of opportunities for improvement, for example is the final report the best method to assess subject specific knowledge? Could collaboration be assessed directly? Could the ability to articulate engineering activities be developed further? When Table 1 and Table 2 are examined it is clear that there is formal supervisor feedback at interim report stage based primarily on the students subject knowledge. While useful and formative in nature at this stage opportunities exist for greater feedback to the students, in areas such as pro-activeness and collaboration.

**Reflection on Current Capstone Format in relation to CDIO Standards**

As illustrated in Table 2 one of the key weaknesses in the current capstone assessment mechanism is in relation to collaboration. While the capstone projects under consideration for this paper are individual projects, this does not mean that collaboration cannot occur. Collaboration and idea generation, feedback on others projects and opinions are a key fundamental to arriving at a solid design concept. Collaboration is directly related to Standard 2 Learning Outcomes, where learning outcomes are reviewed in relation to the interests of the graduates.

When the learning outcomes for the capstone module in question are analysed, collaboration is missing and as the learning outcomes need to be included in-order to encourage the student to illustrate they have the ability to collaborate, if required, to develop creative and original solutions to engineering problems.

Pro-activeness has been identified as a key requirement from Table 2, currently this is assessed through academic supervisor interaction and based on the final report. By analysing pro-activeness through the prism of Standard 8, the capstone project in question should look to hold demonstrations, group discussions and feedback on the content that they have learned.

A key requirement of an engineering graduate is the ability to articulate their opinions, findings and conclusions; currently this is assessed through an oral examination at the end of the project. Standard 5 recommends that students are afforded the opportunity to engage at the various levels of the project, be it the Design stage, Implement stage or Operate Stage.

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Not all capstone projects will offer the opportunity for a physical construction, however all students should be afforded the opportunity to illustrate their ability to articulate their findings. To this end, the assessment mechanism devised to satisfy the student learning requirements, the academic rigour and the accreditation body expectations needs to encompass the above requirements. The following section outlines the proposed assessment mechanism which maps the CDIO standards to the assessment mechanism.

PROPOSED ASSESSMENT

Taking the information above, the key areas to be assessed are collaboration, subject specific knowledge, the ability to articulate and student pro-activeness. This section outlines a proposed Capstone Assessment methodology for measuring these key areas.

- To develop an effective and structured method of providing feedback to the students;
- To develop a suite of assessment instruments that effectively measure the full range of learning outcomes involved in the project;
- To develop a Capstone Project structure that implements these methods in a structured, repeatable and demonstrable manner.

Providing Feedback

To assess the present student perception of feedback (and to attempt to see how this may potentially affect their motivation) a short questionnaire was developed. The questionnaire was based on the Hattie and Tynperly model described above. This is shown below in Table 3. The questionnaire was administered to all (15) current Final Year Project students. Specific questions relating to students perspective of feedback included:

Table 3. Analysis of student perception of feedback

<table>
<thead>
<tr>
<th>Question</th>
<th>Average Score (out of 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The feedback I have received so far has helped clarify the requirements of the project (5 being excellent clarity)</td>
<td>3.8</td>
</tr>
<tr>
<td>The feedback I have received so far has helped me set specific goals for my work (5 being excellent help)</td>
<td>3.6</td>
</tr>
<tr>
<td>The feedback I have received so far has enabled me to adjust these goals as circumstances changed. (5 being very much adjust)</td>
<td>3.6</td>
</tr>
<tr>
<td>The feedback I have received so far has helped me to judge how well I am making progress toward the goals of the project (1 not all, 5 very much helped)</td>
<td>3.2</td>
</tr>
<tr>
<td>Feedback has helped me judge how I should manage my time for the remainder of the project.(1 not at all, 5 very much directed)</td>
<td>3.5</td>
</tr>
<tr>
<td>Feedback has directed me towards areas where I need to improve my skills in order to better complete the project. (1 not at all, 5 very much directed)</td>
<td>3.6</td>
</tr>
</tbody>
</table>

As can be seen from Table 3 it is apparent that the current assessment method does not adequately provide the students with the feedback required to learn, clarify and improve their

Projects. When asked what would they change, students responded varyingly with “Have group meetings for cross-project feedback”, “make presentations”, “Discussion with classmates”, “allow the student to give opinion” but students still seek to have “progress review meetings scheduled by supervisor with written feedback”. A balance therefore is needed between lecturer workload and providing the students with formative feedback to help satisfy learning outcomes of the module.

Students were asked to rank which of the following motivated/demotivated them during their project, results of which are outlined in Table 4. Here students were asked to rank most motivating/demotivating with a 1 down to a 9, therefore the lower the number the more influential the factor.

<table>
<thead>
<tr>
<th>Motivating Factor</th>
<th>Average Ranking</th>
<th>Demotivating Factor</th>
<th>Average Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supervisor's enthusiasm.</td>
<td>4.9</td>
<td>Supervisor's enthusiasm.</td>
<td>4.9</td>
</tr>
<tr>
<td>Personal interest in subject; Relevance to future career; Desire to learn material.</td>
<td>3.5</td>
<td>Personal interest in subject; Relevance to future career; Desire to learn material.</td>
<td>6.4</td>
</tr>
<tr>
<td>Clear objectives; fair grading.</td>
<td>4.4</td>
<td>Clear objectives; fair grading.</td>
<td>2.9</td>
</tr>
<tr>
<td>Supervisor's positive attitude; Approachability; Availability.</td>
<td>4.6</td>
<td>Supervisor's positive attitude; Approachability; Availability.</td>
<td>5.7</td>
</tr>
<tr>
<td>Supervisor's communication of high expectation; Positive feedback and encouragement.</td>
<td>3.0</td>
<td>Supervisor's communication of high expectation; Positive feedback and encouragement.</td>
<td>6.5</td>
</tr>
<tr>
<td>Required participation/attendance.</td>
<td>6.9</td>
<td>Required participation/attendance.</td>
<td>4.3</td>
</tr>
<tr>
<td>Self-motivation.</td>
<td>4.5</td>
<td>Self-motivation.</td>
<td>3.7</td>
</tr>
<tr>
<td>Active learning.</td>
<td>5.5</td>
<td>Active learning.</td>
<td>4.5</td>
</tr>
<tr>
<td>Other</td>
<td>7.5</td>
<td>Other</td>
<td>6.2</td>
</tr>
</tbody>
</table>

From Table 4 it is apparent that positive feedback and relevance to future career are among the most motivational factors for students, while unclear objectives demotivated students. Through the analysis of the current assessment mechanism and student opinion that there are gains in student motivation to be had by altering the current approach to assessment and feedback, the following section details potential changes.

**RECOMMENDATIONS TO CURRENT ASSESSMENT METHODOLOGY**

The aim here is to adjust the assessment instruments used in order to measure a broader range of outcomes and included the following:

**Articulation of Results**

After completion of the project, students should be in a position to synopsise their project concisely and be able to make a short presentation of less than four minutes to audiences of
varying backgrounds and knowledge. Traditional methods of articulation of results and learnings include poster sessions, presentation sessions. However, while useful during assessment, these cannot be reused by students for portfolio or interview. As such the proposal is to ask students to create a sub-4 minute video which outlines their project, with the context being to present the project in a manner which explains the content clearly and concisely to a potential future employer. In response to the student questionnaire it is apparent that students are enthusiastic about this concept, “A video should be included”, “Include a Video/Portfolio”, “An optional video would be good to display working projects”.

**Subject Specific Knowledge**

This is obviously central and fundamental to a capstone project; students are required to manage the project, design and develop a solution and to present this solution in a clear manner. A comprehensive technical report, detailing a clear rationale for the project, a solid foundation for methodology chosen based on comprehensive analysis of appropriate literature and a detailed analysis of work completed. The student needs to articulate that they have grasped a clear understanding of the subject matter, which can be best illustrated in a technical report. However, as Table 3 has indicated, to help the overall project the report should also include reflections on lessons learned collaboration.

**Pro-activeness**

This can be a difficult item to assess; however, it should be on the onus of the student to provide evidence for pro-activeness. This can be combined with the project hub formative feedback (which is described below). What lessons has the student learned from others, what suggestions have they made for others, how did they reflect on the formative feedback and self-assess? Unless we ask the student to do these, it may never occur to them to try. The data can be captured through an online diary of activities which can be presented with the final report and referenced in the final report.

**PROJECT STRUCTURE**

As mentioned previously these are individual capstone projects, separate titles, separate areas of investigation, some design based, some design-build and others simply operate projects. However, this should not limit the ability to collaborate; the proposal is to create a project hub. Here, four capstone students are clustered in a hub as per Figure 2.
From Figure 2, students (identified here by numbers 1 to 4) will be required to provide feedback on each other’s projects, assess each other’s design and collaborate to help find solutions to potential project roadblocks. Evidence of this collaboration needs to be captured and recorded. By capturing evidence of this collaboration the collaboration requirement of the accreditation body, identified in Table 2, is satisfied.

It is proposed that each hub would make 2 presentations per Semester but that rather than all 4 hub members present that a presenter be selected randomly to present not just the work of the others but also the evidence of collaboration. Self-assessment and reflection will form part of this section. The students will also be required to outline the contribution of others towards the collaboration effort. No marks will be awarded for collaboration; however it will form the basis of formative feedback given at the end of Semester 1.

CONCLUSIONS AND FUTURE WORK

This paper has examined a capstone project module through the prism of CDIO, graduate attributes and accreditation body requirements. Weaknesses in areas such as assessment of collaboration and feedback have been identified with a proposed mechanism for addressing these weaknesses established. The motivational impact of positive feedback has been verified through qualitative survey of existing students. The proposed assessment/feedback model will be implemented in the coming academic year and a comprehensive set of metrics implemented to measure the effects of this initiative.

REFERENCES


BIOGRAPHICAL INFORMATION

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SELF-DIRECTED LEARNING IN A RESEARCH COURSE FOR MECHANICAL ENGINEERS

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ABSTRACT

At the University of Twente, students in their third year of the bachelor programme in Mechanical Engineering participate in the course 'Introduction to Technological Research'. The course has a study load of 6.5 ects (182 hours) spread over two quartiles. The course is part of the bachelor completion. During the course students have to engage in literature review on a given topic and write and present a research proposal. During the past years, this course has experienced some major problems with student motivation. Evaluation scores were low and students were leaving the bachelor with a negative image of research practice.

A redesign of the course was made based on the self-determination theory (Deci & Ryan, 2000), a theory on intrinsic motivation. The self-determination theory states that intrinsic motivation of human beings can be stimulated by fulfilling three basic needs; competence, relatedness and autonomy. Based on these three pillars, a new design for the course was made where students were stimulated to take responsibility for their research project by making their own choices, cooperate with peers and completing the full research cycle in close cooperation with one of the research groups at the mechanical engineering department. The first year the redesigned course ran, an extensive course evaluation was used to measure students' appreciation of the course. For this evaluation, a self-designed questionnaire with open and closed questions about appreciation of course elements was used. Results of the evaluation were positive. The majority of students indicated that they liked the course and their research assignment. Students especially appreciated the activities with peers. The overall evaluation score went up from a four to a seven. Based on the evaluation results, minor improvements were made to the course design.

The second year, a validated questionnaire was used to measure student motivation. Results show that intrinsic motivation is moderately high at the beginning of the course but is declining as the course proceeds. Possible causes for this decline are discussed. Also, recommendations are made to other lecturers who would like to stimulate and measure intrinsic motivation in their course or project.
KEYWORDS
Research Skills, Self-directed Learning, Active Learning, Motivation, Peer Review, Course evaluation, Standards 1, 2, 7, 8, and 12.

INTRODUCTION

The University of Twente is a research intensive university, situated in the east of the Netherlands. The University is known as a technical university and also a member of the 4TU federation, but offers both engineering and science programmes as well as programmes in social and management sciences. A total of ± 3.000 staff members and ± 9.500 students work and study at the university, spread over 6 departments. One of these departments is the department of Engineering Technology accommodating the programmes Mechanical Engineering, Civil Engineering and Industrial Design Engineering.

The mechanical engineering (ME) programme is the oldest of the three and exists of a three-year bachelor programme followed by a two-year master specialisation. Annually, approximately 120 students enter the first year of the bachelor. Since 2000, the educational concept of the programme is thematic project education. The bachelor phase is divided into different projects and related courses centred on a content theme (e.g. ‘Energy & materials’ or ‘Designing a consumer product’). This educational concept was taken over in 2001 by Industrial Design Engineering from the start of the programme. During the recent bachelor innovation (2014-2016) the concept was implemented university-wide.

Until the bachelor innovation, ME did not have an individual bachelor assignment, but was finalised in the last semester with a mechatronics project and the course ‘Introduction to Technological Research’ (ITR). ITR is a 6.5 ects (182 hours) course that is spread over the last two quartiles of the bachelor programme. The course is divided into two parts. The first part is a series of lectures on several subjects that have not been taught in the bachelor programme up until this moment: tribology, rubber technology and elastomers. This part is followed by a knowledge test that determines if a student is allowed to proceed with the second part of the course. This second part is aimed at doing research. Students are presented with a global research problem, related to one of the content areas from the first part, for example road contact of rubber tyres. In groups of two students, a literature research is conducted to identify so called ‘white spots’ and formulate a more specific research question. Based on this research question, students write a research proposal that is presented during a closing seminar.

The problem with this course is, that for several years it scored poorly in student evaluations. The overall appreciation score was below 5 on a 10-point scale and students indicated that the two parts of the course did not match with each other. Also, students criticized the assessment method and indicated that they found the course to be demotivating. An additional problem was, that a negative image of research was growing amongst students; an image of research being dull and only theoretical and very remote from daily life.

The author was asked to make a redesign for the course in such a way that students will experience it as a relevant and motivating part of the bachelor programme and gain a more positive image of scientific research. The only condition was to maintain the same study load.
(6.5 ects) and duration (1 semester) of the course. Besides this, the course had to be suitable for a group of approximately one hundred regular students and twenty premaster students. Other limitations were not posed on the redesign.

THEORETICAL FRAMEWORK

As a starting point for the course redesign, several theories on motivation and learning were looked at. Because the course is dealing with third year students who have reached a certain level of maturity compared to for example first year students, also design principles for adult learning were examined. Self-directed learning (Deci & Ryan, 1985) is a theory that is mentioned in relation to adult learning as well as student motivation. When a student is learning in a self-directed manner, he or she is learning from his or her own desire to acquire more knowledge or skills regarding a certain subject.

Deci & Ryan (2002) distinguish four types of motivation that can be present in a learner during a certain learning activity (often in combination with each other, where one or two types are dominant). These four types are:

1) A-motivation (AM): it is not at all clear to the learner why he or she is engaged in a certain learning activity
2) External regulation (ER): the learner is engaged in a learning activity because this is asked or because not doing so will have negative consequences
3) Identified regulation (IR): the learner is engaged in a learning activity because he or she considers this activity to be useful or relevant
4) Intrinsic motivation (IM): the learner is engaged in a certain learning activity because he or she considers this learning activity as valuable, interesting or fun to do

Both identified regulation and intrinsic motivation have an internal drive, meaning that motivation to learn comes from the learner him- or herself (self-directedness). Engagement and commitment to an activity are highest with intrinsic motivation.

Ideally, to have an optimal learning process, every student is intrinsically motivated during all learning activities. However, this ideal is far from feasible. During every educational activity, a mix of the motivation types mentioned above are present in a student. The dominant motivation differs per student and per activity. What is possible however, is to stimulate self-directed learning behaviour by fulfilling certain basic psychological needs of a learner (Ryan & Deci, 2000):

- Autonomy: being able to make your own choices regarding learning method, learning activities, materials and / or learning goals.
- Relatedness: being part of a community and doing something that has a relation to practice or that has value to others (also called relevance or purpose).
- Competence: feeling that the goals that were set are feasible, yet still challenging and seeing one’s progress.
REDESIGN AND IMPLEMENTATION OF THE COURSE

The course redesign was made in cooperation with the programme director of Mechanical Engineering (also co-teaching the course). The basic principles for the redesign were based on the three basic psychological needs (Deci & Ryan, 2000) discussed in the previous section:

- The research experience that the student has in this course should match the research practice within mechanical engineering as much as possible (Relatedness).
- There is a focus on self-responsible learning. The student is hereby able to make his or her own choices regarding content, planning and approach (Autonomy).
- Various possibilities are available for students at various moments to receive feedback on their work (Competence).
- Students learn from and with each other during the course (Relatedness, Competence).

It was decided to let students experience the entire research cycle, from problem statement to presenting the results to an audience. To make room for this, the subject matter related to rubber technology, tribology and elastomers was removed from the course.

The course was divided into two phases. During the first phase, students performed a literature review based on a global problem statement that they received from the research group. Goal of this literature review was to determine what has yet been researched in this specific area and where the so called ‘white spots’ are. Based on this literature research, students formulated a more specific research question. At the end of this phase a literature review and research proposal were handed in. During the second phase, students performed the research according to the plan that was made in phase one. The results of the research were represented in a scientific paper. To conclude the course, this paper was represented at a conference (including lunch and proceedings) where students discussed their findings with each other and answered questions from the lecturers and the supervisors.

All research groups were asked to deliver several research problems with a study load of approximately 4 ects (112 hours) and a supervisor that would be available during the course to supervise the students and provide them with feedback. During the course students worked in groups of two. Besides this, two groups were assigned to each research assignment with the purpose of having a peer partner for each group that was sufficiently familiar with the content of the assignment. Approximately 120 students participated, meaning that more than 30 assignments were needed, divided over the research groups at mechanical engineering (in order to have some flexibility and sufficient choice for students even more assignments were needed, of which some ultimately were not chosen).

During an assignment market, students had the opportunity to gain information with the supervisors about the assignments and make their preferences known. The students were asked to hand in three preferences. A student-assistant was then burdened with the complicated task to divide 120 students (in groups of two) in such a way that as many students as possible were assigned to the research assignment of their first or second choice. In most cases this succeeded. Where it wasn’t possible to give students an assignment of their preference, a different assignment was chosen in consultation with the students, for example an assignment with the research group of their first choice.

Parallel to the research process, a series of lectures and tutorials was organised. During these lectures students learned about different aspects of doing scientific research: searching and reviewing scientific information, academic writing and research ethics. Besides general theory and guidelines, a lot of examples from the research practice at mechanical engineering were presented. Educational methods during these lectures were varied and active. Lectures were given by the author and the programme director as well as several guest lecturers with expertise in one of the topics.

In both phases of the course, a ‘peer review session’ was planned during which groups that were working on the same research assignments take a critical look at each other’s work and give (content related feedback). The goal of this peer review is threefold:

a) Students learn to look critically at the research of another group and doing so, will also look critically at their own work.

b) It matches the research practice where peer review is common practice (e.g. when handing in a paper for a journal).

c) A limitation of the time that supervisors have to spend on giving feedback to concept versions.

Besides this, both phases also contained a feedback session where the supervisor from the research group met with all students that were doing an assignment from this group. A series of walk-in lectures were planned throughout the course. These were not filled-in beforehand but were used as a possibility for students to ask questions, information on specific topics or feedback on specific parts of their work.

During the course, students are free to choose their own way of working. The only ‘hard’ deadlines are the deadline at the end of the first part (for handing in the proposal) and the deadline at the end of the second part (for delivering the paper). For the peer review and feedback sessions, it was not specified what had to be handed in. This could be a complete draft paper, but also just an introduction section. Emphasized was, that these feedback moments were planned to help them and that it was up to them to determine to what extent they wanted to use these. What was also emphasized was, that in principle everything was possible (e.g. altering the assignment, purchasing some materials for an experiment, extension of a deadline) as long as the students were proactive and took initiative to arrange things themselves.

Table 1 below represents the different parts of the redesign, divided by the basic need they address.

<table>
<thead>
<tr>
<th>Autonomy</th>
<th>Relatedness</th>
<th>Competence</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Assignment choice</td>
<td>• Real assignment for ME research group</td>
<td>• Peer review</td>
</tr>
<tr>
<td>• Own planning and way of working</td>
<td>• Examples from ME research practice</td>
<td>• Regular feedback from supervisors</td>
</tr>
<tr>
<td>• Walk-in lectures</td>
<td>• Walk through full research cycle including</td>
<td>• Feedback from lecturers</td>
</tr>
<tr>
<td>• Room for own ideas and initiative</td>
<td>presentation of results</td>
<td>• Conference presentation</td>
</tr>
</tbody>
</table>

Table 1. Redesign components categorized by basic need
METHOD

The first year redesigned the course ran, it was evaluated by means of an extensive questionnaire including open as well as closed questions. The questionnaire contained for example questions about the different aspects of the course, the supervision, working with peers and the assessment method. The questionnaire was placed on the learning platform (Blackboard) of the course and was administered twice; once half-way the course (after the proposal was handed in) and once at the end of the course. Finally, an evaluation meeting with all supervisors was held to capture their experiences and suggestions. Besides this, lecturers were asked for their classroom observations. Based on the evaluation results, small improvements were made for the second year.

The second year the redesigned course was conducted, a different evaluation approach was used. Instead of measuring student perception and course appreciation by using an extensive course evaluation questionnaire, student motivation was measured by using a validated Situational Motivation Scale questionnaire (SIMS) existing of 16 multiple choice questions (Guay, Vallerand, & Blanchard, 2000). This questionnaire measures the combination of the different types of motivation present in a learner during a learning activity, as described in the theoretical framework. Based on these outcomes, the degree to which a student is participating in an educational activity because he or she wants to be (self-determination) can be established. This was done three times during a lecture at the start, the middle and the end of the course. The questionnaire was combined with two open ended questions asking students what they liked and did not like about the course. Also, students were asked to grade the course on a scale from one to ten.

RESULTS AND IMPROVEMENTS

In this section, first the results of the extensive course evaluation questionnaire that was administered during the first year of the redesigned course are presented, followed by the improvements made to the course and results of the SIMS questionnaire that was administered during the second year.

**Course evaluation questionnaire (year 1)**

The course evaluation questionnaire was filled in by students at the end of the third quartile (n=46) and at the end of the fourth quartile (n=33). Results were positive. After the first part of the course, 50 percent of the students indicated that they liked the course, 43.5 percent were neutral. After the second part, 60.6 percent liked the course and 30.3 percent were neutral. Regarding the research assignments, after the first part 73.3 percent of the students indicated that they found their assignment fun to do, 13 percent were neutral. After the second part 72.7 percent found their assignment fun to do, 9.1 percent were neutral.

<table>
<thead>
<tr>
<th></th>
<th>Liked the course (%)</th>
<th>Assignment fun to do (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Positive</td>
<td>Neutral</td>
</tr>
<tr>
<td>Quartile 3</td>
<td>50.0</td>
<td>43.5</td>
</tr>
<tr>
<td>Quartile 4</td>
<td>60.6</td>
<td>30.3</td>
</tr>
</tbody>
</table>

Table 2. Student appreciation of the course and their assignment

Most students (80.4 percent in quartile 3 and 75.8 percent in quartile 4) valued the things that were learned during the course as ‘relevant for a mechanical engineer’. Students indicated to be satisfied with the supervision of the lecturers.

During quartile three, most students were satisfied with the supervision received from the lecturers (69.5 percent) and their supervisors from the research groups (60.9 percent). During the fourth quartile this dropped somewhat with 57.6 percent being positive about the lecturers’ supervision and 51.5 percent about the supervision received from their research group supervisor.

### Table 3. Student appreciation of supervision

<table>
<thead>
<tr>
<th>Supervision from lecturers (%)</th>
<th>Supervision from research group (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>Neutral</td>
</tr>
<tr>
<td>Positive</td>
<td>Neutral</td>
</tr>
<tr>
<td>Quartile 3</td>
<td>69.5</td>
</tr>
<tr>
<td></td>
<td>21.7</td>
</tr>
<tr>
<td>Quartile 4</td>
<td>60.9</td>
</tr>
<tr>
<td></td>
<td>36.4</td>
</tr>
</tbody>
</table>

Almost all students were positive about working in pairs (91.3 percent in quartile 3 and 93.9 percent in quartile 4) and also about working with two pairs on the same assignment (91.3 percent in quartile 3 and 93.9 percent in quartile 4).

### Table 4. Student appreciation of group work

<table>
<thead>
<tr>
<th>Working in pairs (%)</th>
<th>Working with two groups on the same assignment (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>Neutral</td>
</tr>
<tr>
<td>Positive</td>
<td>Neutral</td>
</tr>
<tr>
<td>Quartile 3</td>
<td>91.3</td>
</tr>
<tr>
<td></td>
<td>4.3</td>
</tr>
<tr>
<td>Quartile 4</td>
<td>93.9</td>
</tr>
<tr>
<td></td>
<td>3.0</td>
</tr>
</tbody>
</table>

The peer review sessions were appreciated positively by most of the students. After the first part of the course, 69.6 percent of the students indicated that they found the peer review useful. 43.5 percent of the students found the activity fun to do. After the second part, again 69.6 percent of the students found it useful. Almost half of the students (48.5 percent) found it fun to do.

### Table 5. Student appreciation of peer review session

<table>
<thead>
<tr>
<th>Peer review useful (%)</th>
<th>Peer review fun to do (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>Neutral</td>
</tr>
<tr>
<td>Positive</td>
<td>Neutral</td>
</tr>
<tr>
<td>Quartile 3</td>
<td>69.6</td>
</tr>
<tr>
<td></td>
<td>43.5</td>
</tr>
<tr>
<td>Quartile 4</td>
<td>69.6</td>
</tr>
<tr>
<td></td>
<td>48.5</td>
</tr>
</tbody>
</table>

The peer review sessions were valued positively by most of the students. After the first part of the course, 69.6 percent of the students indicated that they found the peer review useful. 43.5 percent of the students found the activity fun to do. After the second part, again 69.6 percent of the students found it useful. Almost half of the students (48.5 percent) found it fun to do.
The final conference was only evaluated after quartile 4. About half of the students (48.4 percent) found the conference fun to do, 27.3 percent were neutral.

The main criticism about the course was about the book. After quartile three, 15 percent of the students were positive about the book (45.7 percent were neutral). After the fourth quartile, 0 percent of the students were positive and only 9.1 percent were neutral. All others (90.1 percent) were negative.

The overall course as graded (on a scale from 0 to 10) with a 6.9 for the first part and a 7.0 for the second part.

Answers to the open ended question ‘What did you like about this course?’ varied a lot. The aspects most mentioned were: the final conference (n=7), the possibility to choose from different assignments (n=8) and getting acquainted with doing research (n=11). Suggestions for improvement that were mentioned most were focused on the consistency of the assessment between supervisors (n=6) and on the book (n=8).

**Minor improvements**

Based on the evaluation results of the first year of the redesigned course, some small improvements were made to the course. The book was replaced for a different one and a set of hand-outs on practical skills needed for the course (e.g. paper writing and academic English).

To enhance consistency between assessments of different supervisors, the assessment formats for the research plan and paper were improved and discussed in a meeting with the supervisors. Finally, some measures were taken to strengthen the link with practice. Guest lecturers were added to present interesting examples from ME research practice. Also, more emphasis was placed on the societal impact of research. A guest lecturer from the philosophy department was invited to give an inspirational lecture about the topic and students were asked to integrate societal impact into their research proposal and paper.

**SIMS questionnaire (year 2)**

The SIMS questionnaire was filled in by students at the start of the course (n=79), halfway through the course (n=56 and at the end of the course (n=55). Below, the results from the three measurements are represented in a table and a graph.

<table>
<thead>
<tr>
<th></th>
<th>Start</th>
<th>Halfway</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number respondents (N)</td>
<td>79</td>
<td>56</td>
<td>55</td>
</tr>
<tr>
<td>Intrinsic Motivation (IM) (µ)</td>
<td>4.2</td>
<td>3.9</td>
<td>3.7</td>
</tr>
<tr>
<td>Identified Regulation (IR) (µ)</td>
<td>4.8</td>
<td>4.5</td>
<td>4.4</td>
</tr>
<tr>
<td>External Regulation (ER) (µ)</td>
<td>4.9</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>A-motivation (AM) (µ)</td>
<td>2.2</td>
<td>2.5</td>
<td>3.0</td>
</tr>
</tbody>
</table>
When we look at the results of the SIMS questionnaire, we can see that at the beginning of the course, intrinsic motivation and identified regulation are fairly high, but that external regulation is also high. From the start of the course motivation is mixed, with a focus on the self-directed types of motivation. During the course however, intrinsic motivation and identified regulation decrease and a-motivation increases. This is in line with the grades the students give to the course. At the beginning of the course the average grade is 6.9, decreasing to a 6.6 halfway the course and a 6.4 at the end of the course. Even though the decrease is small, motivation and course appreciation of students are going down as the course proceeds.

Answers to the open ended questions halfway the course are varied. Aspects students liked about the course were conducting the research experiment and experiencing research in practice (n=22), the freedom of choice and independency (n=13), gaining insight in the world of scientific research (n=10) and the assignment itself (n=8). To the question ‘What did you not like about the course?’ comments were made mostly on uncertainties regarding expectancies or how to approach the assignment (n=9), the writing process (n=8), the assignment and its results (n=6) and problems with supervision (n=6). At the end of the course, the same aspects were emphasized. What was added were comments about the amount of guest lectures and their direct relevance for the course work (n=16).

DISCUSSION

Results showed that besides internal types of motivation, external motivation is also high. A possible explanation for this is, that doing research is just not something that appeals to the
average bachelor students at mechanical engineering. They tend to prefer the more technical
courses and projects and picture themselves working as a designer or technical consultant
rather than as a scientific researcher. Also, this course is (together with a mechatronics
project) the last course students have to pass in order to obtain their bachelor degree. This
might also add to the feeling that this is something they have to do instead some something
they that is by itself fun and interesting.

Besides this, we can see that in the second year the redesigned course ran, intrinsic
motivation and course appreciation were decreasing, where it stayed stable during the first
year. An explanation could be that a different group of students can react differently to the
same course activities. During the first year, about 20 percent of the students were
premasters who generally are a bit older and have a higher intrinsic motivation than the
regular bachelor students. During the second year the premasters were participating in a
separate course for premaster students and not part of the regular bachelor course anymore.
Also, during the second year, we decided to let students work more independently and have
less guidance during the walk-in lectures. At the same time, there were some problems with
absent supervisors and we decided to have less coordination meetings with the supervisors
to take away some of the workload for everyone. Perhaps this combination of less
coordination and problems with supervisions made students feel like they were ‘thorn into the
deep end’ too much as some commented in the open questions.

Adding the quest lectures was not very successful. Especially in the second half of the
course, students felt that there were too many and that they did not directly contribute to the
course work. This might also explain the decrease in course appreciation.
Some students were disappointed because the assignment, that seemed very interesting at
first, turned out to be not what they expected or became frustrating when experiments failed,
causing their motivation to go down.

Finally, the SIMS questionnaire is a measurement of the state of someone’s motivation at a
certain moment (snapshot in time). It is also possible that at the moment of the measurement
students were less happy because they were struggling on writing the paper or getting their
measurements right before the deadline. This could strongly affect someone’s motivation at a
certain moment. A standard course evaluation looks back on a longer period where the
frustration that was experienced at certain moments has less influence on how one
appreciates the whole course.

CONCLUSIONS AND RECOMMENDATIONS

Using the self-determination theory as a basis for redesign and focusing on the three
psychological basic needs ‘Autonomy, Competence and Relatedness’ did help to design a
course that was more motivating for students. What worked well was the freedom of choice
(Autonomy), the peer learning and peer feedback (Relatedness / Competence) and the link
with the real research practice of mechanical engineering (Relatedness).

This is however no guarantee for having intrinsically motivated students. I remains a quest
for what works and it is often hard to predict how students will react to changes made. Giving
more autonomy to students works well, but giving too much autonomy can give students the
feeling that they are left alone. The same goes for inspiring examples from practice. These can be very motivating, but without a direct link to the course work in combination with a high workload, they can be perceived as a waste of time and demotivate students. Using the SDT as a basis for redesign can offer guidance for thinking about more motivating methods and approaches in a course. For this course we will continue to follow this path to self-determination, keep the successful things and replace the unsuccessful for new ideas in consultation with students.

Some recommendations for lecturers who also would like to make their course more self-directed:

- Look where you see possibilities to offer students choices in content, working methods or materials. Make sure to combine this with clear structure and guidance so students don’t get lost in their options and responsibilities.
- Peer review is a good way to let students give feedback on each other’s work. Students learn from each other, but will also start to look critically at their own work while comparing with others. Using a format based on the assessment criterial will help students to focus their feedback on the relevant aspects.
- Think about ways to make a link with professional practice. This could be an assignment for a real client, but it could also be done with an excursion, experiences from practice (e.g. from alumni) or examples of current applications.
- Use a combination of motivation measurement with a standard course evaluation to help you interpret the results. The SIMS questionnaire is one example, but there are also other options, for example on the SDT website (University of Rochester, c2017).
- If you would like to get inspired and know more about motivation theory, there are several books available that give a compact and accessible summary of scientific findings on motivation and applications in practice, for example Deci & Flaste (1996) and Pink (2011).
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BIOGRAPHICAL INFORMATION

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CDIO IN THE DESIGN OF A NON-ENGINEERING PROGRAM

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ABSTRACT

Integrating the core areas of the health, natural, social and management sciences, the Master in Development Practice program P.PORTO will provide students with the substantive knowledge and practical skills required to analyze and diagnose the multidimensional challenges of sustainable development such as extreme poverty, climate change and infectious disease. It is part of a global network of similar programs and it involves faculty from all P.PORTO schools, as well as external organizations.

The design of such a multidisciplinary program is a challenge. Though it is not an engineering program, one of its educational objectives is the practice of a problem solving and development process. Thus, it was decided to leverage on ISEP’s experience with CDIO and use it to support the MDP program design.

In this paper, it will be provided a short description of the program and its objectives and it will be explained how CDIO was used in the program’s design process.

KEYWORDS

Development Practice, Sustainable Development Goals, Program Design, Pedagogical Patterns, Standards: 2, 3, 5, 7, 8

INTRODUCTION

The Polytechnic of Porto (P.PORTO) is a Portuguese public higher education institution created in 1985 by joining several independent higher education institutions, some of them over 100 years old. Instituto Superior de Engenharia do Porto (ISEP) is a 164 years old engineering school and has been a member of the CDIO Initiative since 2008. With over 18500 students P.PORTO is the largest and most highly regarded Polytechnic in Portugal. It stands out for its ability to instruct young people with the knowledge necessary for the working market, able to contribute to economic development with a high sense of social responsibility.
This institution stands out for its interdisciplinarity, covering a wide spectrum of scientific knowledge, such as Engineering, Music and Performing Arts, Education, Accounting and Administration, Management and Technology, Health, and Tourism.

P.PORTO also has a long history of collaboration and support of Non-Governmental Organizations (NGOs), both in Portugal and in Africa.

The Master in Development Practice (MDP) intends to be an interdisciplinary master degree program offered by P.PORTO's that prepares students to better identify and address the challenges of sustainable development. This MDP program consist of two years of coursework in four intersecting macro disciplines areas - health, natural, social, and management sciences -- combined with cross-sectorial field training. The program is scheduled to start in the 2017/2018 school year with a maximum of 25 students.

The MDP program will be a part of the global network of MDP programs offered by universities and collaborating organizations and have been developed according to recommendations outlined in the final report of the International Commission on Education for Sustainable Development Practice (2008). It is led by the Earth Institute of the Columbia University, New York. CDIO members Tsinghua University (China) and Trinity College Dublin (Ireland) already offer MDP programs in this network.

PROGRAM OVERVIEW

The MDP program is designed for: Generalist development practitioners; Specialist development practitioners; Policy administrators and policy professionals; Private-sector professionals and Educators.

Integrating the core areas of the health, natural, social and management sciences, the MDP program will provide students with the substantive knowledge and practical skills required to analyze and diagnose the multi-dimensional challenges of sustainable development such as extreme poverty, climate change and infectious disease.

The two years MDP curriculum includes:

- Core courses in the health sciences, natural sciences, social sciences and management sciences;
- Global Classroom: Foundations of Sustainable Development Practice (FSDP) course that fosters cross-border and cross-disciplinary collaboration;
- Electives or additional credits in the core courses;
- Field training experiences that provide students the opportunity to gain first-hand experience of integrated development approaches within the real-world context;
- Intensive pre-MDP preparation where students may need to take additional courses if they have not fulfilled prerequisite requirements in areas such as chemistry, biology, economics, math or statistics.

Global Classroom: Foundations of Sustainable Development Practice (FSDP) is a blended-learning course that fosters cross-disciplinary collaboration and allows students and teachers
from around the world to participate in collective assignments and learning experiences. Global Classroom was initiated at the Earth Institute, Columbia University, in 2008. The first edition addressed a broad range of core issues, including health, economics, policy, agriculture, ethics, and education. Students from around the world are assigned the same readings and then can join their classmates for live sessions with global experts.

**CDIO CONTRIBUTION TO PROGRAM DESIGN**

It is a challenge to design a program with so many different people involved, so we resorted to CDIO to provide the framework for program design and operation. Though it is not an engineering program, the core of MDP is a problem solving and project development process, i.e. CDIO. The full stack of CDIO standards was applied in the MDP program design.

**Syllabus**

The MDP program follows some general guidelines common to all MDP programs in the network, especially covering many of the UN Sustainable Development Goals (SGD). As such, each host HEI's can customize their program to meet local needs and objectives. Since the MDP program it is not an engineering program and has quite broad objectives, more akin to a social sciences one, the extended CDIO Syllabus 2.0 (Crawley et al., 2011) was used as template for the program’s syllabus. No major changes were needed in section 2 and 3.

Section one was structured according to UN Sustainable Development Goals, instead of Math, Science and Engineering subjects. The 8 schools delivering the program defined two sets of priorities, i.e. a subset of SGD goals the program should focus on: one short term, to be immediately in the program; and long term, that they expected to start being covered or partially covered in a 5-year time-frame. So, section one has two subsections, one with core SGD goals and one with supplementary goals.

Regarding section 4, subsections 4.3 to 4.7 focus on the Conceive-Design-Implement-Operate in an engineering perspective, thus they had to be adapted to the broader objectives of the MDP program. Direct references to “Engineering” were removed and the content trimmed. Subsections 4.5.2, 4.5.3 and 4.5.4 were eliminated.

**Integrated Curriculum**

The MDP program’s curriculum is depicted in Figure 1. It includes 3 types of courses:

- Personal and interpersonal skills (blue) – Management Science I, Management Science II, Global Citizenship and Education and Contemporary Global Problems.
- Disciplinary knowledge and its application in professional engineering (red) – Global Health and Development I, Global Health and Development II, Engineering for Sustainable Development I, Engineering for Sustainable Development II, and two elective courses.
The program’s curriculum is structured so that the student continuously improves its competences and skills in dealing with the challenge of addressing UN SGD’s. Following a spiral approach to curriculum design, the first semester is focused on analyzing problems and identifying solutions; the second encompasses designing a plan for action and manage its implementation, including assessment; and the third extends to plan implementation and operation. Each semester builds on the previous ones, fostering curriculum integration.

**Design-Implement and Integrated Learning Experiences**

The MDP program’s learning process uses the experiential learning model (Kolb, 1984). As such, the product, process and operating skills courses are paramount for the learning process, as they provide the student the opportunity to work in real challenges and apply the knowledge and skills acquired in the other courses. The Foundations I and II courses provide two especially interesting design-implement experiences, as there is the possibility that students from multiple MDP programs across the world can create multidisciplinary teams and collaborate in solving a challenge.

Field Practical combines practical work in an organization, where the student will experience firsthand the challenge of implementing a real project in a real organization, with critical assessment and brainstorming. MDP students participate in “hands-on” field-training sessions of up to three months’ duration. Beginning after completion of the first academic
year, they constitute a structured, “clinical” training program, giving students the opportunity to gain first-hand experience of integrated development approaches in a real-world context. Students may work in Africa, Asia, or Latin America, for example, in teams dedicated to solving development challenges. With careful input from collaborating MDP organizations, appropriate development projects for students to join are identified. Site visits, meetings, lectures, and other academic events are examples of activities that may be organized to complement the students’ fieldwork.

Students, on completion of their field training, reflect on their experiences, prepare a consolidated field-training report, and may provide recommendations for addressing the complex development challenges that they encountered in the field. They offer a comprehensive analysis of local conditions, explain possible measures for reducing poverty, and suggest a roadmap for working toward sustainable development.

The program management is quite aware that the implementation of this integrated learning process is a challenge, but the program is expected to have a maximum of only 25 students per year.

**Active Learning**

MDP program lacks the strong disciplinary content of a traditional engineering program. The program aims to combine social sciences, management and engineering to provide the student the tools to solve problems in a challenging multicultural environment. In this context, the program aims to have students with diverse backgrounds and regards this as an asset to be exploited in the learning process. Therefore, the learning process is mostly based in active learning methods, but also includes some project based learning.
Active learning means different things to different people, so that it would be useful to have a reference/catalog for active learning methods. The Pedagogical Patterns Project (PPP) has produced the book "Pedagogical Patterns Advice for Educators" (PPEB, 2012) to try to capture the expertise of teaching practice/learning in a compact form that can be easily communicated to those who need the knowledge. Many of the pedagogical patterns in the book are focused on active learning. Figure 2 provides a mind map of the active learning patterns in the book.

The MDP program management used the ISEP framework for pedagogical patterns’ use (Martins et al., 2016) to identify pedagogical patterns classes/subclasses and a few wide-ranging patterns (e.g. Embrace Correction**) that should be dominant in the program. They act as pedagogical guidelines the faculty should use when designing the courses’ learning...
processes. The active learning pedagogical patterns classes/subclasses to be promoted in the MDP program are highlighted in Figure 2.

This approach doesn't mean that all patterns in class should be used or that patterns in another class can't be used. These are mere guidelines. The actual set of all patterns to be used in a course may be dependent on a lot of factors (e.g. subject, student background experience and knowledge, project characteristics, etc.) and may even evolve during the course in order to improve learning effectiveness.

**Figure 3. MDP program's pedagogical patterns**

The set of reference pedagogical patterns classes/subclasses and pedagogical patterns in the MDP program are depicted in Figure 3. At institution level, the definition of policies for a program or encompassing multiple programs is a key instrument for pedagogical coordination. The indication of pedagogical patterns classes considered "best practices" helps translating the documented policies and objectives into comprehensible implementation goals, but still generic and flexible at the implementation level. A program’s pedagogical approach is a specialization of the educational policies of the institution. At this level, one should resort to pedagogical patterns classes/subclasses and, possibly, to a few wide-ranging patterns. At the course level, pedagogical patterns are used to describe the operational implementation of different types of classes and assessment. Though the set of used patterns may not be restricted the classes of patterns defined for the course and the institution, it is natural that most patterns will fall within these classes.
The pedagogical patterns classes/subclasses and pedagogical patterns in the MDP program reflect the multidisciplinary nature of the program and aims at to leverage the diverse background and aims of the students.

CONCLUSION

We can conclude that it is possible to apply the CDIO framework to support the design of a non-engineering program. Some adaptations were required, especially in sections 1 and 4 of the CDIO Syllabus (v2.0), and standards 4 – Introduction to Engineering - and 6 – Engineering Workspaces - were not used. Standards 9 to 12 were out of the scope of this phase of the project, but they will be used in the operation phase of the program.

Faculty from non-engineering schools had no problem in understanding CDIO and were even eager to use it, especially the Syllabus. Some of them were familiar with active learning and experiential learning, so they found the use of the CDIO framework quite helpful.

ISEP pedagogical patterns framework was also used to foster the design of a coherent learning process involving faculty from so many schools.

REFERENCES


BIOGRAPHICAL INFORMATION

Eduarda Pinto Ferreira, PhD. She is an Auxiliary Professor of Mathematics at ISEP - Instituto Superior de Engenharia do Porto, Portugal. PhD in Optimization. Chairman of 1st CDIO Iberian Workshop (ISEP), March 2011. Chairman of the 3rd ESICUP Meeting (EURO Special Interest Group on Cutting and Packing), international conference in Porto (ISEP), March 2006. Member of the Scientific Committee of JBLE-09 (Jornadas Luso-Brasileiras de Engenharia), Porto (ISEP), February 2009. President of ISEP’s Pedagogical Council between 2010 and 2014. President of the NGO IPP Solidário since January 2016. Attended almost all CDIO conferences since 2008 and lead the organization of the 2016 Fall meeting in Porto.

Ângelo Martins, PhD. He is an Auxiliary Professor of Computing at ISEP - Instituto Superior de Engenharia do Porto, Portugal. Since 2008 has been the program manager of the Informatics Engineering BS program, the largest ICT program in Portugal, which is EUR-ACE accredited. He is the scientific coordinator of the Computer Graphics and Information Systems unit of INESC TEC, the Portuguese largest research lab on computing and electrical engineering with over 1000 researchers. He is also the national representative on the European Commission Digital Skills and Jobs Sub-Group. He is CDIO enthusiast and has been involved in CDIO since 2008.

José Carlos Quadrado, PhD. He is a full professor with tenure and is currently the immediate past-President of ISEL and the Vice-President of ISEP. Holds the position of past-President of the International Federation of Engineering Education Societies (IFlEES) and the position of past president of the Ibero-American Engineering Education Association (ASIBEI). Currently he is a President of the Latin American and Caribbean Consortium of Engineering Institutions (LACCEI) and a member of the board of the European Society for Engineering Education (SEFI). He is also a past-Vice President of SEFI. He leads the Portuguese Observatory on European and Latin-American University management strategy best practices (TELESCOPI Portugal) and is the past-President of the Portuguese association of engineering deans (APDI2E). He was a member of the general assembly of the European Network for Accreditation of Engineering Education (ENAEE), and has been actively supporting the development of accreditation agencies in Central Asia and Latin America.

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WHY UNIVERSITIES WANT TO JOIN CDIO?

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ABSTRACT

The CDIO initiative started in 2000 with four universities, in 2011 there were already 62 schools and today there is more than 120 universities. The growing number of universities in CDIO shows that the initiative provides something that the engineering programs, schools, faculties and universities are looking for. The CDIO initiative can be seen as an innovation aiming at improving engineering education. An innovation is an idea, practice, or object that is perceived as new by an individual or other unit of adoption. The characteristics of an innovation, as perceived by the members of a social system, determine its rate of adoption: relative advantage, compatibility, complexity, trialability and observability. Universities planning to join CDIO initiative are thus operating with an innovation having these general characteristics. But what are universities thinking when they are applying to join CDIO initiative? Why do universities want to join CDIO? One way of answering these questions is to look deeper in their application documents that universities produce during the application process. The applicant universities answer in the CDIO questionnaire a set of questions such as "Why does your university want to join the CDIO Initiative?" and "How do you expect CDIO to impact these programs?". To understand how the applicant universities perceive CDIO initiative as an innovation 55 CDIO applications from 2010 to 2016 were analyzed using content analysis. Based on the analysis we can conclude that universities see CDIO approach very positively. The approach is expected to have remarkable impact on engineering education, the CDIO approach connects well with earlier development activities in the universities, it provides tools for development and it is a network for learning and sharing experiences.

KEYWORDS

Join CDIO, CDIO application, Innovation characteristics, Standards: 1-12

INTRODUCTION

The CDIO initiative started in 2000 with four universities, in 2011 there was already 62 schools and today there is more than 120 universities. The growing number of universities in CDIO shows that the initiative provides something that the engineering programs, schools, faculties and universities are looking for. At the moment, the procedure to apply for a
Membership in CDIO initiative is quite simple. The first part of the procedure is as the Knowledge stage in the Innovation-Decision process (Rogers, 2003): the university should learn what CDIO is and how the CDIO approach functions. The details of the procedure are described in the CDIO website (http://cdio.org/participate/join-cdio). The CDIO application provides information on the applying university and their plans in education development. For example, the applicant provides information about their motives for joining the CDIO Initiative, which programs they plan to apply CDIO, what are their future plans for education and what is their experience in education development.

Rogers (1995) defines an innovation as an idea, practice, or object that is perceived as new by an individual or other unit of adoption. The universities planning to join the CDIO initiative are thus operating with an innovation: The CDIO initiative (CDIO, 2016) can be seen as an innovation aiming at improving engineering education. To be more precise, we should actually speak about an organizational innovation. It refers to the creation or adoption of an idea or behavior new to the organization (Daft, 1978; Damanpour, 1996). The CDIO approach is not only an innovation rather it is an organizational innovation which is perceived new by a program, school, faculty or university.

The characteristics of an innovation, as perceived by the members of a social system, are one important explanation of the rate of adoption of an innovation. The generalized characteristics of an innovation produced by several studies are relative advantage, compatibility, complexity, trialability, and observability. Other factors affecting an innovation’s rate of adoption are 1) the type of innovation-decision, 2) the nature of communication channels diffusing the innovation, 3) the nature of the social system in which the innovation is diffusing and 4) the extent of change agents promotion efforts in diffusing the innovation. Still, most of the adoption rate of an innovation is explained by five characteristics. The general characteristics of an innovation are described in the table below. Basically, an innovation is more adaptive when these characteristics are present. Only exception is the Complexity, which is negatively related to the adoption – less complexity and more simplicity is key to the adoption of an innovation. (Rogers, 1995, 2003)

Table 1. Innovation characteristics (Rogers, 2003).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Relative advantage</td>
<td>Relative advantage is the degree to which an innovation is perceived as better than the idea it supersedes.</td>
</tr>
<tr>
<td>Compatibility</td>
<td>Compatibility is the degree to which an innovation is perceived as being consistent with the existing values, past experiences, and needs of potential adopters.</td>
</tr>
<tr>
<td>Complexity</td>
<td>Complexity is the degree to which an innovation is perceived as difficult to understand and use. Any idea may be classified on the complexity-simplicity continuum.</td>
</tr>
<tr>
<td>Trialability</td>
<td>Trialability is the degree to which an innovation may be experimented with on a limited basis.</td>
</tr>
<tr>
<td>Observability</td>
<td>Observability is the degree to which the results of an innovation are visible to others.</td>
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</tbody>
</table>
In this research, these characteristics were searched from the applications of the potential CDIO universities. The research aimed to recognize which elements of the CDIO approach are the ones that attract new universities – which characteristics of the innovation are important to the applicants.

In the next section, the research approach is explained. The results are reflected using the innovation characteristics after the research approach. Finally, the paper discusses and concludes the key findings.

**RESEARCH APPROACH**

The research question this paper has is “What is the motivation of universities to join CDIO?”. The research question is answered through the presented innovation characteristics – what are key characteristics that attract universities to join CDIO initiative.

The data for this paper comes from the CDIO applications that universities have done. The CDIO application normally contains three different elements: the application, self-evaluation and supporting letters. This study focused on the actual application, which gives answers to the predefined set of questions. The universities joining CDIO know that their applications will be widely reviewed by other CDIO member universities. During the application process the applicant university is all the time identified – it is not a blind review. In this research the university connection is removed and only the texts provided in the applications are used.

Altogether 55 CDIO applications from 2010 to 2016 were analyzed. The analyzed applications are such that the author had some connections either through the role of acting as a regional leader in the European region or applications that the author has been reviewing otherwise. The research data is from the “Why does your university want to join the CDIO Initiative?” question of the CDIO application questionnaire.

The answers of the 55 applications were collected in a MS Access database. Content analysis was used to analyze the answers of the applications. Content analysis is a research technique for systematically analysing written communication such as in this paper the CDIO application represents (Weber, 1990). It allows the researcher to analyze relatively unstructured data in view of the meanings, symbolic qualities, and expressive content (Krippendorff, 2012). In content analysis, all answers are processed and interesting and relevant information is collected. The collected information was categorized using the five innovation characteristics presented earlier. The presented results follow the original characteristics and their definitions except using term Simplicity instead of Complexity, because the collected information refer to innovation Simplicity rather than Complexity.

The research approach had some limitations. First, the applications analysed were not randomly selected rather it was a fixed set of applications available. Second, some of the provided quotes of the applications might be difficult to understand why they are placed under some category. The quotes are taken from a longer text context and this might make them to look somehow problematic. Third, this study focused only on the first question of the CDIO applications although the applications might have provided relevant information elsewhere in the applications too.

*Proceedings of the 13th International CDIO Conference, University of Calgary, Calgary, Canada, June 18-22, 2017.*
RESULTS

The analyzed applications came from 22 different countries mostly from the CDIO European region. Most applications came from Russia, Finland and Sweden.

The universities applying to CDIO provided several reasons for their interest in joining CDIO initiative. The reasons were classified according to the five characteristics of an innovation presented earlier in Table 1. All five characteristics were identified in the applications as can be seen at the Table 2 showing the frequency of the reasons. Altogether 169 reasons to join CDIO were provided. On average each university had three reasons for their willingness to join CDIO. Three categories covered almost 80 % of the reasons.

Table 2. Frequency of the reason to join CDIO.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative advantage</td>
<td>43</td>
<td>25 %</td>
</tr>
<tr>
<td>Compatibility</td>
<td>41</td>
<td>24 %</td>
</tr>
<tr>
<td>Simplicity</td>
<td>14</td>
<td>8 %</td>
</tr>
<tr>
<td>Trialability</td>
<td>25</td>
<td>15 %</td>
</tr>
<tr>
<td>Observability</td>
<td>46</td>
<td>27 %</td>
</tr>
</tbody>
</table>

Reasons to join CDIO: Relative advantage

Category “Relative advantage” was the second most common category of reasons found in the applications. The reasons emphasized the suitability and superiority of CDIO initiative for engineering education. The applications had reasons such as:

- The CDIO framework is a good model for engineering education that stresses product lifecycle
- CDIO is a valuable standard for our engineering education
- The university has identified the CDIO initiative to be the leading force and international cornerstone in the innovation of engineering education
- The CDIO approach is probably the most direct and wise one.

Many applications underlined the impact that CDIO can make to their programs. Others stressed the overall impact on their development such as

- That can guide us in our long-term and comprehensive development work for all our engineering programmes
- An urgent need for a new model for engineering education
- This is what we are searching for to help us better educate our students
- The joining with CDIO Initiative gives us a chance to fast and efficient rearrangement the whole education system
- We, as a faculty, are convinced that CDIO will help us fulfil our educational mission.
Others emphasized the impact on the quality of their education:

- The main reason for coming is the need to improve the quality of engineering education by reform of educational programs
- With the aid of CDIO initiative we can guide and support our development work towards higher quality education that is relevant to the working life
- The need to improve the quality of engineering education by reforming educational programs.

Universities mentioned the impact on the working life relevant too:

- The students trained with the CDIO skills will be even more attractive to regional and national companies and businesses
- The CDIO standards and framework can help us be more systematic in reviewing our programs, for further improving the education with the goal of graduating better engineers for industry.

**Reasons to join CDIO: Compatibility**

The reasons to join CDIO in the category “Compatibility” polarized in two main reasons: Fit to the university/program vision and similarity of the university/program development activities with the CDIO approach. The statements stressing the fit to the university/program vision included following expressions for example:

- Fit well with the School of Engineering’s Goals and Values
- One that fits our vision.
- We realize that our philosophy is very much in line with that of CDIO
- The CDIO initiative seems to correspond well to that vision.
- The CDIO framework resonates with several distinctive features of our university.
- CDIO Initiative alignment corresponds with the fundamental orientation of the university to combine academic education, scientific research and practical usage of deep knowledge.
- We find that the CDIO’s initiative is consistent with the university vision
- The CDIO concept at the one side fits perfectly well into our engineering profiles and philosophy.

The similarity of the CDIO approach and the development activities of the university/program were underlined strongly as well:

- The CDIO process of project based curriculum development and ongoing review is consistent with the ideals
- We believe our philosophy in teaching design and manufacture aligns very well with the CDIO approach.
- Our design teaching approach follows some of CDIO principals to stress engineering fundamentals set in the context of conceiving, designing, implementing and operating of real-world systems and products.
• The development process and the bachelor curriculum turn out to be very much in line with the CDIO approach and meet many of the CDIO Standards
• For more than twenty years we have continually developed our engineering programmes placing much focus on a close relationship with industrial partners, particularly regarding students working in integrated projects.
• University already may be quite close to the CDIO concept in some aspects.
• University of Technology has taken large steps to develop the education provided, based on theories of learning and on implementing a pedagogic idea inspired by the CDIO standards.
• The CDIO philosophy has a good fit with the activities of the department
• Joining CDIO will thus contribute to the university’s on-going efforts.

Reasons to join CDIO: Simplicity

In the original model, term Complexity was used, but since the applications clearly emphasized the simplicity not the complexity as a reason to join CDIO. This category had the smallest amount of hits, but still there were a number of reasons listed that clearly show that CDIO approach is not difficult to understand and use. The applications underlined the non-complexity i.e. simplicity of the CDIO approach by saying for example:

• The CDIO has 12 standards which serve as guidelines for educational program reform
• The CDIO standards and framework can help us be more systematic in reviewing our programs
• The CDIO model has a comprehensive and logical methodology for imparting to the students a broad base of knowledge, skills, and attitudes necessary to become successful young engineers
• The CDIO could give a solid and structured approach to further catalyze our development work
• The CDIO initiative provides a framework with clear standards that can guide the designers of the curriculum to achieve their goals
• Supplies a systematic setup for both documentation of the programmes as well as defining the type of programme.

Some applications stressed that CDIO is clearly focused in engineering education and thus it is easier to understand:

• The CDIO framework is a good model for engineering education that stresses product lifecycle:
• The CDIO approach is clearly focused on engineering students.

Reasons to join CDIO: Trialability

Only 15 % of the reasons to join CDIO initiative were categorized to “Trialability”. These reasons formed four additional groups dealing with staff inspiration, standards and syllabus, framework for activities and going beyond engineering education. The applications emphasized CDIO as a framework for their activities, a framework to try CDIO:

• The CDIO framework provides a detailed and well-structured guide
• The CDIO initiative provides us with excellent tools and methods
• These efforts are greatly helped by a systematic framework for education development.
• And CDIO offers a concise framework for new curriculum development
• Membership of CDIO would provide a structured framework for the future teaching within the Department of Engineering
• Gives us the perfect framework to develop our program so that we can provide our students with skills and competences they need to be able to compete on global work markets.

Many applications underlined the role of CDIO standards and syllabus too to start using CDIO:

• Syllabus to provide them additional value
• Its syllabus helps us to truly support students in the development of their professional identity.
• We see that CDIO standards are the powerful and helpful manual for the education improvement and reforming.
• The CDIO has 12 standards which serve as guidelines for educational program reform.

The applications mentioned staff inspiration and testing CDIO outside engineering programs as reasons to join CDIO too:

• Furthermore it will inspire staff and students to improve the quality of teaching and learning at the university.
• Apply the CDIO standards and skills to the engineering programmes but also to the degree programmes that are not traditionally referred to as engineering programmes.

**Reasons to join CDIO: Observability**

Category “Observability” was the most common category of reasons found in the applications. These reason focused on learning from the others, sharing own experiences, visibility and availability of information, and network of universities sharing the same idea of education development.

The applications underlined learning from the experiences of the universities/programs which have been doing CDIO several years already:

• We are interested to learn from the best practices and innovative ideas from the collaborating partners in the CDIO organisation
• To learn from leading engineering educators worldwide
• Gain from the wider perspective of CDIO and experience from other institutions
• The association with CDIO is the best choice for us to obtain new experience from leading engineering educators on a world scale
• Benefit from the extensive experience of CDIO leaders
• We also believe that membership in CDIO will provide us with a broader perspective on Engineering Education.

At the same time many applications emphasized their willingness to share their own experiences and to contribute to the CDIO network:

• We also believe that our university’s unique character and geographical position in Russia will allow us to make a significant contribution to the CDIO network
• We have also something to give to the CDIO community.
• We will be able to test our ideas for innovations by sharing them with CDIO partners.
• We are ready to share our experience and to develop it with the CDIO participants.
• To share the experience with the other universities
• The CDIO framework gives us an appropriate environment to share our experiences.

The applications highlighted the visibility and openness of CDIO initiative. Information on CDIO is available and background investigations are possible before making the decision to apply CDIO membership. The applications provided followings statements regarding these ideas:

• After doing research on CDIO for over a year
• There have been much successful experiences showing that the CDIO approach is practicable and executable.
• The CDIO framework is also tried and tested in tens of universities within a long period of time.
• It has been an effectively international initiative to reform the education of undergraduate engineers.
• CDIO initiative is used globally
• Furthermore we liked the philosophy of sharing knowledge, cases and experiences with other universities and we like to become a member of this global initiative.
• Our cooperating partners participate actively in the educational programmes.
• When we read the first documents about CDIO we found that there are many structured responses to our educational needs.

Finally, the importance of a large network sharing same ideology of engineering education was emphasized as well:

• The CDIO connects together many universities or schools of engineering sharing the perception of what the main engineer’s skills should be
• Working together with the community
• To join CDIO so that we can learn from and contribute to the approach with other like-minded schools.
• We wish join a network where we can meet people with similar ideas, share experiences and find ways to continuously improve our education programs,
• An existing network where experiences and ideas can be shared and discussed is considered to be a very important aspect of joining the initiative.
• The CDIO initiative provides collaboration with schools having a similar philosophy and approach.
DISCUSSION

The applications of universities applying the CDIO membership provide interesting information on the reasons why they are joining CDIO initiative. This information is interesting for those universities that are thinking about applying CDIO initiative. They can study the rationale other universities used and they might identify new viewpoints with their application too.

The reasons categorized well into the general characteristics of an innovation as the CDIO initiative was understood. The study shows that the reasons universities have in their applications are pretty similar. However, there are differences on how universities emphasized their reasons to join the CDIO initiative. Three major categories represent almost 80% of the reasons. One of the key reasons to join CDIO is observability which can be understood as learning from the others, sharing own experiences, visibility and availability of information about CDIO, and becoming a member of a network of universities sharing the same idea of education development. Another major reason to join CDIO is the CDIO initiative’s compatibility with the university’s own vision on education development and with the development actions already taking place. The third major category of reasons to join CDIO is the relative advantage universities are looking to achieve through CDIO initiative. Universities see the CDIO initiative as suitable and superior for engineering education. They are looking for remarkable impact on their programs and overall development. Furthermore, the universities see that the CDIO initiative is not a complex system rather it can be easily understood and tools such as the CDIO standards and the CDIO syllabus are simple to work with.

The study offers interesting information for universities that are already CDIO members too. These universities can reflect their own membership on the reasons that the new universities see important. Based on this information the current CDIO members can analyse their activities in the CDIO network. They can be more active in the network, they can focus on their actions in areas that are seen important and they can communicate the CDIO initiative better to new universities too.

For the CDIO leaders, the study showed how applying universities perceive the CDIO initiative. It seems that the perception is quite positive and correct. The elements CDIO initiative is emphasizing are seen important in the applications too. The CDIO initiative aims for better engineering education by providing a system and tools i.e. CDIO Standards (Bennedsen, Georgsson, & Kontio, 2016; CDIO, 2017a) and Syllabus (CDIO, 2017b) to support quality enhancement. The CDIO initiative is a network of universities and active individuals that share the same enthusiasm of improving engineering education.
CONCLUSIONS

The study identified the key characteristics of the CDIO approach that are attracting new universities to join the CDIO initiative – which characteristics are important and relevant to the applicant. These characteristics are presented below in the Table 3. Each characteristics of the CDIO approach are connected with the characteristics of an innovation.

Table 3. The key characteristics of the CDIO approach.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Key characteristics of the CDIO approach</th>
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<tbody>
<tr>
<td>Relative advantage</td>
<td>Suitable and superior for engineering education</td>
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<tr>
<td></td>
<td>Remarkable impact on the development</td>
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<td>Compatibility</td>
<td>Similarity to university vision</td>
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<td></td>
<td>Connectivity with earlier development activities</td>
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<td>Simplicity</td>
<td>Easily understood</td>
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<td></td>
<td>Focus on engineering education</td>
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<td></td>
<td>Tools for development (Standard &amp; Syllabus)</td>
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<tr>
<td>Trialability</td>
<td>Inspires staff</td>
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<td></td>
<td>Standards and syllabus available for testing</td>
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<tr>
<td></td>
<td>Framework for development activities</td>
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<td></td>
<td>Not limited to engineering education</td>
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<tr>
<td>Observability</td>
<td>Network to learn from the others</td>
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<td></td>
<td>Network to share own experiences</td>
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<tr>
<td></td>
<td>Visibility and availability of information</td>
</tr>
<tr>
<td></td>
<td>Network of similarly-minded universities</td>
</tr>
</tbody>
</table>
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BIOGRAPHICAL INFORMATION

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PEDAGOGY FOR EVIDENCE-BASED FLIPPED CLASSROOM – PART 1: FRAMEWORK

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ABSTRACT

This paper presents a pedagogical framework for designing a flipped classroom using an evidence-based approach supported by the use of info-communication technology tools. It firstly explains the swift rise in the flipped classroom approach, and suggests that the main reason for adopting flipped classroom is to address the learning needs of today’s learners – the millennials. It argued that the traditional ways of lecturing is no longer compatible with the learning needs of these learners. It offers some explanations of resistance by faculty to adopt the flipped approach despite the apparent benefits it offered. Next, the paper argues for a comprehensive framework for an evidence-based to flipped classroom, using sound pedagogy and understanding based on how humans learn. It points to the lack of pedagogic understanding underlying the design of flipped classroom. Specifically, the paper put forward the following heuristics: (1) Good learning design is always grounded on evidence-based practice, incorporating Core Principles of Learning; (2) Information-communication technologies are used strategically and creatively to enhance specific aspects of the learning process, (3) The completed blended learning design maximizes the affordances of a range of learning modes and mediums. Using these heuristics, the paper then shares a model of flipped classroom which we feel is applicable for adoption in any given discipline. The paper explains the key features of the framework, focusing in detail how the core principles of learning are being applied to the design, delivery and assessment aspects of flipped classroom. In addition, the thoughtful use of info-communication technologies (ICTs) to support flipped classroom is also explained. The paper then provides a discussion on the present status of flipped classroom, and concludes with a reminder that the flipped classroom approach still warrants further investigations. It calls for continual improvement of the approach using the framework proposed.

KEYWORDS

Flipped Classroom, Evidence-based Approach, Info-Communication Technology, CDIO Standards 8 and 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 as "faculty" in the universities.

INTRODUCTION

It appears that the adoption of flipped learning or flipped classroom is accelerating at an ever-increasing pace. The Flipped Learning Network reported in 2014 that: “Although not a scientific measure, a search in Google in June 2014 resulted in 244,000 hits for the term “Flipped Learning” and 1,690,000 links for “flipped classroom”. Using the same terms in Google Scholar, the number of hits resulted in 314 and 2,530, respectively” (Yarbro et al, 2014). The authors’ own Google search on August 8, 2016 yielded the following: 4,120,000 results for the term “Flipped Learning” and 557,000 results for “flipped classroom”. Using the same terms in Google Scholar, the number of results are 67,600 and 32,400; respectively. The Horizon Report 2015: Higher Education Edition listed flipped classroom as one of the digital strategies with very promising potential – with a time-to-adoption horizon of “one year or less” (NMC, 2015).

WHAT IS FLIPPED CLASSROOM?

Essentially, flipped classroom entails students watching a pre-recorded video and/or other activities such as reading a journal article, visit to a place of interest prior to attending class. The video can be the lesson created by faculty, or other professionally-made titles or educational resources made publicly available via sites such as YouTube. Students are then given opportunity to evaluate their own learning for example via automated quizzes, discussion board posts, or assignments to be reviewed in class. When in classroom, students interact face-to-face with both faculty and peers, thus becoming more active participants in the learning process rather than listening passively to lectures. Faculty designed interesting in-class activities that leverage on the pre-class preparatory work and challenge students in applying higher-order activities such as problem-solving, evaluating designs and decision-making. Faculty can therefore commit precious class-time to monitoring student performance and providing useful formative feedback (e.g. Kim et al, 2014; Hughes, 2012; Zappe et al, 2009).

In terms of Bloom’s taxonomy, under the flipped model, the lower levels (‘remembering’ and ‘understanding’) are presented before class through recorded lectures and videos, and other materials. These provide the foundational support for learning so that in-class time can be spent working on higher levels of learning from ‘applying’ to ‘creating’. This is shown in Figure 1.
Proponents of flipped classroom offered many benefits of flipped classroom, which reported on better student academic attainment, retention, etc. It is our argument that all the above are outcomes is not unique to the flipped classroom approach; rather it is an outcome that can be expected from any good pedagogic design, especially when it is applied in the context of today’s learners in a technologically advanced, rapid-changing world. In fact, we tend to concur with Kim et al (2014) who reasoned that perhaps the most compelling reason is the need to adapt to the learning needs of today’s students, often referred to as millennials – individuals born between 1982 and 2002 (Oblinger, 2003; Wilson & Gerber, 2008). This generation is distinguished by their access to technological and collaborative experiences. Characteristics of millennial students include 24/7 information connectedness, preference for environments that support multi-tasking, authentic learning experiences, and gravitation toward group activity and appreciation of the social aspects of learning (McMahon & Pospisil, 2005). They also demonstrated the need for instant gratification and low tolerance for delay, especially for long lectures. For a long time, there had been questions from educators and educational researchers on the effectiveness of teaching methods that are entirely lecture-based (Barr & Tagg, 1995). Numerous writers had called for a move beyond the lecture by employing methods that are more active, cooperative, and learner-centered (e.g. Bonwell & Eison 1991; Felder & Brent 2009; Lambert & McCombs 1998). However, as noted by Bligh (2000), despite innovations in technology enabling alternative techniques for pedagogy and continued criticism, the lecture method continue to be the primary method for teaching. He argues that they are as effective, but not more effective, as any other teaching method in transmitting information, and “are ineffective in stimulating higher order thinking”. Ritchhart, Church, & Morrison (2011) noted that educators and researchers have come to recognize the “complexities of teaching and learning for understanding as opposed to just knowledge retention”.

Flipped classroom, with its main focus on active learning in the classroom, is useful in addressing these challenges. Standard 8 “Active Learning” in the CDIO Standard noted: “Active learning methods engage students directly in thinking and problem solving activities. There is less emphasis on passive transmission of information, and more on engaging students in manipulating, applying, analyzing, and evaluating ideas…. Active learning is considered experiential when students take on roles that simulate professional engineering practice, for example, design-implement projects, simulations, and case studies”.

The flipped classroom also fits well with the rationale for Standard 8, which is worth repeating here: "By engaging students in thinking about concepts, particularly new ideas, and requiring them to make an overt response, students not only learn more, they recognize for themselves what and how they learn. This process helps to increase students' motivation to achieve program learning outcomes and form habits of lifelong learning. With active learning methods, instructors can help students make connections among key concepts and facilitate the application of this knowledge to new settings”.

Despite the increasing popularity of flipped classroom, not every educator is comfortable with the approach. Shimamoto (2012) noted that though simple enough to understand, flipped classrooms are not quite as simple to implement due the range of technical skills, conceptual knowledge, and pedagogical expertise required to execute varying aspects of the method. Newton & Hes (2013) cautioned that if ill implemented, flipped classroom can throw up unexpected repercussions across the subject content and delivery. Some educators may obviously lack the skill – or more accurately, courage – to try their hands on flipped classroom. Some may still hold rigidly to the belief that students should be responsible for their own learning to the extent that they ought to be able to figure out for themselves how to learn. Some may not be comfortable in the “role change” from one of “purveyor of knowledge” to one of coaching students in their learning.

More importantly is the issue of educator who may have mistaken notion of flipped classroom, for example, by simply make a video-recording of his/her lessons and continue to teach the same way when in classroom. Garrison & Kanuka (2004) paraphrased Marshall McLuhan as saying “it is not enough to deliver old content in a new medium”. Ash (2013), in writing about the benefits and drawbacks of flipped classroom, quoted Andrew Miller, an educational consultant who works with the Alexandria, Virginia-based professional development group ASCD and the Novato, California-based Buck Institute of Education, as saying “My concern is that if you're still relying on lecture as your primary mode of getting content across, …you haven't done anything to shift the type of learning that's occurring... Just because you flipped your classroom doesn't mean your students will watch the videos”. Ramsey Musallam, from Sacred Heart Cathedral Preparatory, a private Catholic high school in San Francisco, agreed and noted that “what you're looking at is simply a time-shifting tool that is grounded in the same didactic, lecture-based philosophy. It's really a better version of a bad thing." (Ash, 2013). Agreeing, Bull, Ferster & Kjellstrom (2012) noted that “the effectiveness of this approach depends on the skill and pedagogical strategies you use. You can't magically transform an ineffective lecture by transferring it to video”.

These findings may not be that surprising – as in any new pedagogical approaches, few educators have direct experience with it, and early adopters are largely rely on their own experience to guide the process, learning what does and doesn't work well for them (Crews & Butterfield, 2014). In their review of flipped classroom implementation, O'Flaherty & Phillips (2015) highlighted that the key obstacle of faculty in designing, implementing and evaluating the effectiveness of their flipped classrooms is a lack of pedagogical understanding of how to effectively translate the flipped classroom concept into practice. Hamdan et al (2013) argued that teachers do recognise the value of using sound pedagogical approaches to enhance the student experiences through curriculum renewal, but need support to develop skills needed to effectively guide the systematic use of technologies and translate conceptual thinking into planned learning sequences.

THE NEED FOR PEDAGOGY FOR FLIPPED CLASSROOM

There is henceforth a strong need to establish a pedagogically sound approach to implement flipped classroom. Although various authors agreed that there is no one way for classroom flipping (e.g. O’Flaherty & Phillips, 2015; Jarvis et al, 2014; Tucker, 2012), we felt that this is inconsequential – more importantly is the understanding of what flipped classroom entails. The important feature of flipped classrooms is not that they are new, or that they represent a move away from traditional lectures, or even that they use technologies. Rather, the issue is that flipped classroom approaches combine pedagogy and learning technologies in ways that extend to large numbers of students’ opportunities for deep learning through application and consolidation (Sankey & Hunt, 2014).

Several authors (e.g. Brame, 2013; Kim et al, 2014; Reyna, Davila & Huber, 2016) offered suggestions for successful implementation of flipped classroom. However, mostly of them are guidelines, lacking the systematic approach grounded in theoretical considerations. Few attempts had been reported, which include: (1) Oste et al (2014) who proposed using the design science approach of Peffers et al (2006) and Briggs’ (2006) theory-driven design approach to design a flipped classroom for the their information system classes; (2) Green (2015) who used grounded theory (Glaser & Strauss, 1967) and Gerstein’s (2012) 4-phase model of flipped learning to developed a framework for implementing flipped classroom in marketing education; and (3) Kelly & Barrette (2015) who proposed the FLICS (Flipped Learning-Centred Interactive Classroom Strategy) model based on the seven principles of good teaching and learning from Chickering & Gamson (1987) applied to Buemi’s (2014) “microflips”.

Added to this is the on-going debate on the effectiveness of flipped classroom. This issue will not be dealt with here (for more in-depth discussion, see Cheah & Sale, 2017). Suffice to note here is in recent years, there have been calls for education to follow other fields such as medicine and agriculture and embrace the use of evidence as a foundation for adoption of programs and practices (Slavin, 2008). Grocica & Buskist (2011) defined EBT as “the conscientious, explicit, and judicious integration of best available research on teaching technique and expertise within the context of student, teacher, department, college, university, and community characteristics.” In EBT, evidence is used to: (1) in a diagnostic capacity improve the focus of our teaching, (2) in a motivation capacity to focus students’ attention on their strengths and weaknesses, (3) as a means of program assessment to improve programming and planning, and (4) as a means of communicating student achievement to report on an assessment (Bruniges, 2005).

In the next section we present our own framework on the pedagogy for evidence-based flipped classroom. It is derived from an extensive synthesis of a wide range of knowledge bases relating to human learning by the first author, resulting in a set of key heuristics or core principles of learning, which, and together with high effect size intervention approaches (Marzano, 2007; Hattie, 2009; Petty, 2009), underpin highly effective teaching, and forms the basis of our framework for evidence-based flipped classroom. And satisfies the criteria of great pedagogy suggested by Husband & Pearce (2012). The pedagogic framework permits teaching professionals to thoughtfully plan learning experiences from a more evidence-based perspective in a wide-range of educational contexts (Sale, 2015).

PEDAGOGICAL FRAMEWORK FOR EVIDENCE-BASED FLIPPED CLASSROOM

The development of our framework is based on the following broad heuristics for effective and efficient teaching and learning approach (Sale, 2015):

1. Good learning design is *always* grounded on evidence-based practice, incorporating Core Principles of Learning
2. Information-communication technologies are used *strategically* and *creatively* to enhance specific aspects of the learning process
3. The completed blended learning design *maximizes* the affordances of a range of learning modes and mediums

Sale’s Core Principles of Learning (Sale, 2015) cover the following:

1. Motivational strategies are incorporated into the design of learning experiences
2. Learning goals, objectives and proficiency expectations are clearly visible to learners
3. Learners prior knowledge is activated and connected to new learning
4. Content is organized around key concepts and principles that are fundamental to understanding the structure of a subject
5. Good thinking promotes the building of understanding
6. Instructional methods and presentation mediums engage the range of human of senses
7. Learning design takes into account the working of memory systems
8. The development of expertise requires deliberate practice
9. A psychological climate is created which is both success-orientated and fun
10. Assessment practices are integrated into the learning design to promote desired learning outcomes and provide quality feedback

In addition to incorporating all of the above features, our flipped learning framework also explicitly integrated the high effect size instructional strategies (Hattie, 2009) as well as the use of educational technology tools (EduTech tools) to not only facilitate student learning both online and in the classroom, but also to evaluate the effectiveness of the flipped classroom implementation by focusing on faculty reflection and student feedback on their learning experience. Our framework is shown in Figure 2. The outermost ring is the ultimate aim of teaching: to engage students in their learning. The next ring shows the use of core principles of learning in the design of learning tasks, with emphasis on use of EBT and sustained effort at continual improvement via course evaluation and lecturer’s personal reflection. The next circle highlights learning designs that promote learning in both the pre-class or online (or out-of-class) and in-class components: the use of high effect size strategies (Hattie, 2009), collaboration between learners set in contexts that mimic real-world scenarios, to create content by collaborating with other fellow students. The learning process is supported by effective facilitation and timely feedback from the lecturer. The next inner circle shows 2 important factors that affect the support the learning in flipped classroom: the learning environment and use of EduTech tools. Lastly, note that our framework does not claim to be exhaustive or summative as new knowledge and insights will continually enhance our understanding of human learning and the implications of how we teach and how students learn.

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DESIGNING AN EVIDENCE-BASED FLIPPED CLASSROOM

The design of any flipped classroom and its associated learning tasks should be constructively aligned (Biggs, 2003). Application of the core principles of learning permits the attainment of the required constructive alignment that facilitated learning. Furthermore, while each core principle focuses attention on a key area or process relating to how humans learn and the specific implication for design of learning tasks, they are not discreet or separate in that they should be considered independently of each other. They are in fact, mutually supporting, inter-dependent and potentially highly synergistic (Sale, 2015).

The design of flipped classroom should always stay focus on the learning tasks that we want students to do in classroom. This should have a clear focus of learning objectives to be achieved, including the level of proficiency to be attained (Principle No.2). This can be done by giving careful considerations to specific learning outcomes as often detailed in module syllabi, using Bloom’s taxonomy for example. The learning objectives should be based on key concepts and principles necessary for students to obtain a good grasp of the subject matter to be mastered (Principle No.4). The learning tasks should not be overwhelming (e.g. too many concepts, too much factual information, too abstract, etc) that it taxed the learner’s cognitive ability to make sense of what is being covered. This entails a good understanding of how our memory works, in particular the working memory (Principle No.7). One good way to achieve this is via “chunking” (Miller, 1956), or the splitting of content into manageable sizes, to facilitate the assimilation of information in the working memory. Even more effectively, some of these smaller “chunks” are based on some prior knowledge that students...
already acquired from other modules. Subsequent “chunks” of new information to be learnt are then skillfully weaved into the learning task so that new learning will result (Principle No. 3). More importantly, in the context of encouraging students to prepare themselves before coming to class, the learning tasks must be interesting enough that they are willing to invest time in going through them. This is especially true for the online component of flipped classroom, which need to be more than just postings of video recordings of the usual lectures. As such, motivational strategies must be incorporated into the design of learning tasks (Principle No.1). Effective and creative use of EduTech tools (more to be discussed below) can be a way to increase students’ motivations.

Having designed the learning tasks, next comes the delivery of learning tasks. Here it is worth repeating the learning goals, objectives and proficiency expectations to the students (Principle No.2). It is imperative that instructional methods and presentation mediums engage the range of human of senses (Principle No.6). Also very important is the role played by the learning environment, where it is recommended by Principle No.9 that a positive psychological climate is to be created so as to promote student participation, both online and in-class. Sale (2015) offered the strategy based on SHAPE – Stories, Humor, Activities, Presentation Style and Examples – for creating desirable learning environment. In addition, the approach of “chunking” and building on prior knowledge also serve to build up students’ confidence in learning the subject. This is especially useful for fostering collaborative learning among students. This approach also facilitates students’ thinking process (Principle No.5).

Lastly, in terms of evaluating student learning, Principle No.10 emphasized the use of quality feedback to students as formative assessment. These, coupled with clear expectation of learning outcomes (Principle No.2), deliberate practice (Principle No.8) and conducive learning climate (Principle No.9) serve to motivate students to take responsibility for monitoring their own learning.

All the above can be supported by appropriate use of EduTech tools. In the context of this paper, EduTech tools refer to the freely available Web 2.0 Tools as well as specialized computer simulation and modelling softwares for use in teaching and in enhancing student learning. Although the above-mentioned core principles of learning did not make explicit references to use of info-communication technologies (ICTs) in general or EduTech in particular, their use is particularly noticeable in several core principles. For example, in Principle No.10 for facilitating the assessment process, EduTech tools immensely useful in delivering constructive feedback to students, often in real-time. EduTech tools can certainly be used to create learning materials that can engage a range of human senses. Helping students make connections to prior knowledge (Principle No.3) can be achieved via web site links to earlier topics. Similarly, elaborate topics can be divided into smaller segments and delivered via manageable “chucks” and integrated via hyperlinks. EduTech can also support Principle No.9 by including in the learning process elements of play, for example time-sensitive online quizzes. EduTech tools can also be used to promote good thinking (Principle No.5) but as noted by Sale (2014), we need to be clear from a pedagogical point of view about the types of thinking that we are trying to promote and provide practice in, as technologies themselves do not ensure good thinking.

It is important to note, however, that right from the beginning, we are very mindful to put “pedagogy before technology” (Watson, 2001). As noted by Schneider et al (2013), learning
from educational technology is beneficial when the technology is designed as a function of the target content and built on a strong foundation in relevant learning theories. Likewise, Ascough (2002) asserted that “the use of technology should be driven by sound pedagogical principles. Sound pedagogy is essential to the effectiveness of all our teaching, no matter what the content or mode of delivery.”

An example of how the above framework is used for implementing flipped classroom for a core module in a Diploma in Chemical Engineering is illustrated in a separate paper (Cheah, Sale & Lee, 2017).

DISCUSSIONS

Flipped classroom is still a relatively new phenomenon in today’s educational arena. Tucker (2012) cautioned: “Given education’s long history of fascination with new instructional approaches that are later abandoned, there’s a real danger that flipping, a seemingly simple idea that is profound in practice, may be reduced into the latest educational fad. And, in today’s highly polarized political environment, it also runs the risk of being falsely pigeonholed into one of education’s many false dichotomies, such as the age-old pedagogical debate between content knowledge and skills acquisition.”

Flipping a classroom is a continuous process and must be investigated as such to determine variables related to student learning and the flipped classroom approach including the content itself, the age level of the students, the technology and methods used to implement the approach (Connor, Newman & Deyoe, 2013). As noted by Newton & Hes (2013), the transformation of teaching to that of a flipped is a change that requires strategic alignment of many factors including space, pedagogy, assessment, IT infrastructure and student expectations. Although much had been learnt about it, much more remains to be explored, for example, the impact of learning environment, students’ intrinsic motivation, promoting out-of-class collaboration in the online component, etc are some of the areas worthy of future educational research.

The design of flipped classroom concerns determining what curriculum components and specific learning outcomes can be effectively and efficiently met in the online environment, and what can be better facilitated in a face-to-face context, i.e. the “balance of the blend” (Sale, 2015). Being a relatively new teaching approach, there are some unanswered questions on flipped classroom. Weimer (2014) coined the word “flippant” attitudes about flipped classroom and raise the following concerns:

- Who should be taking flipped classes – first year students or seniors?
- Does the content of some courses flip more successfully than content in other courses?
- What criteria do we use when deciding what content to flip?

A review by Cheah & Sale (2017) showed that many diverse fields of study had adopted flipped classrooms. There are authors who opined that the flipped model “likely does not work in all contexts” (e.g. Crews & Butterfield, 2014; Yarbro, et al, 2014). And there are also those who suggested adopting some form of “partial” flipped approach (e.g. James, et al, 2014; Swift & Wilkins, 2014), which may include “flippable moment” (Honeycutt, 2014). However, as noted by Garrison & Kanuka (2004), the real indicator of effective blended
learning is not the amount of face-to-face or online learning, but their effective integration within a programme to deliver meaningful learning experiences. This is supported by the work of Ginns & Ellis (2007) that drawn from a large body of seminal research, which asserted that the approaches students taken to learning, and the subsequent quality of their learning, is closely related to their perceptions of their learning experience. It is therefore our assertion that if the design process as outlined above has been appropriately negotiated, this issue is really only a matter of practicality and creativity.

CONCLUSION

In this paper we have presented a framework that we believe is useful to guide any lecturer who wants to embark on the flipped classroom journey. We have used the above framework (Figure 2) to design an evidence-based flipped classroom for a core module in the Diploma in Chemical Engineering. Details of the work done are presented elsewhere (Cheah, Sale & Lee, 2017). We have also conducted an evaluation of the flipped classroom the findings of which are also presented elsewhere (Cheah & Sale, 2017). We trust that our framework is a most comprehensive attempt to date to address the exciting, multi-faceted nature of flipped classroom using an evidence-based approach. It is useful not only in guiding lecturers interested in trying out flipped classroom, but also for those who are carrying out education research in the efficacy of flipped classroom.

As noted by Miller (2012), flipped classroom is only a start: “The focus should be on teacher practice, then tools and structures. The flipped classroom is one way to help move teachers toward better teaching but does not ensure it.” He noted that while it may be true that learning is today’s context is still largely dictated by the needs for examinations, and that materials learnt today will be useful when one graduated, these reasons do not engage the students who are already struggling to find meaning and relevance in school. If the flipped classroom is truly to become innovative, then it must be paired with transparent and/or embedded reason to know the content (Miller, 2012). This clearly points to the need for more research in flipped classroom.
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BIOGRAPHICAL INFORMATION

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EFFECTIVE UNDERGRADUATE DESIGN-BUILD-TEST PROJECT IMPLEMENTATION: THE NEED FOR A COMPREHENSIVE CHECKLIST OF SELF-EVALUATION CRITERIA

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ABSTRACT

The basis of a checklist for Problem-Based Learning (PBL) type Design-Build-Test (DBT) experiences already exists in the form of the CDIO syllabus. Guidelines for effective implementation via a systematic approach to designing and operating such experiences have been defined within the CDIO community. However, a narrative review of conference papers in the CDIO knowledge base suggests low instances of disseminated DBT projects published that refer to a comprehensive range of CDIO syllabus outcomes, or make reference to an implementation methodology.

Previous meta-analysis attempts to determine the efficacy of PBL in engineering education, outside of the CDIO community, have been hindered by variability in structure and implementation across different institutions. Consequently, the uncertainty of positive outcomes and the necessary paradigm shift in the approach to teaching required when switching to PBL have acted as inhibitors to the further development of best practice.

Based on the premise that checklists are a simple yet effective means of ensuring that best practice is followed, this paper sets out to promote the use of a self-evaluation checklist for effective PBL implementation, and for periodic review as part of a process of continual improvement. Widespread adoption of such a checklist would consequently bring greater standardization to the descriptions of DBT projects among CDIO collaborators (and others), so that further research into effective implementation might be enhanced. It is therefore proposed that the version 1.0 checklist presented here acts as a foundation that might further be utilized by communities of interested engineering education practitioners involved in DBT activities.

KEYWORDS

Checklist, PBL, DBT, CDIO Syllabus, CDIO Standard 5

INTRODUCTION

Problem Based Learning (PBL) advocates cite the development of a range of personal, interpersonal and professional skills in addition to the opportunity to apply disciplinary knowledge in an environment, which mimics professional practice, as being among the benefits of such an educational approach (Lamancusa et al, 2008; Edström & Kolmos, 2014). PBL students have been shown to find such problem based experiences challenging, motivating and enjoyable (Clavert & Laakso, 2013). Programs featuring significant amounts of PBL also tend to benefit from higher retention rates (Kolmos, 2010). The skillsets developed in a PBL based curriculum are highly prized by industry, which also enhances students’ employability prospects. In the context of engineering education, PBL is commonly realized through design implement experiences, which are a fundamental element of a CDIO curriculum and are defined by Standard 5 (Crawley et al, 2007).

Effective implementation of PBL however is not a simple matter and not always executed well. The formation and management of project groups can be difficult and students in dysfunctional groups have found the experience painful (Kjersdam, 1994). Faculty members often do not have experience of managing similar projects in an industrial setting (Lamancusa et al, 2008) and are also often unfamiliar and uncomfortable in the role of mentor or coach, which is considered preferable for PBL, compared to their normal role of lecturer (Elger et al, 2000; Malmqvist et al, 2004; Taylor et al, 2001). There are also infrastructural issues such as access to appropriate workspaces for the construction of prototypes. Indeed, some meta-analyses of PBL have found significant variation among implementations, negative effects where PBL was implemented poorly by non-expert tutors (Prince, 2004) and less knowledge acquired by students on PBL programs when tested by exams (Dochy et al, 2003); although significantly this knowledge was found to be retained better when retested at a later date. Such variations in implementation and hence uncertainty of positive outcomes, along with the necessary paradigm shift required in teaching approach and associated resources could all be factors inhibiting more widespread adoption of PBL.

Problem-Based Learning (PBL) has its origins in medical education of the early 1970’s, initially introduced at McMaster University in response to bored students’ dissatisfaction with being asked to remember vast amounts of information, which they perceived had little relevance to medical practice (Barrows, 1996). The methodology spread quickly as educators recognized benefits such as student motivation and stimulation which were subsequently confirmed by meta-analyses (Albanese and Mitchell, 1993; Vernon and Blake, 1993). Barrows (1996) noted that while implementations of PBL varied between institutions, the original six point core definition at McMaster worked well as a basic model for comparison:

1. Learning is student centered
2. Learning occurs in small groups
3. Teachers are facilitators or guides
4. Problems form the organizing focus and stimulus for learning
5. Problems are the vehicle for the development of [clinical] problem-solving skills
6. New information is acquired through self-directed learning

The authors contend that this definition from medical education applies equally well to PBL in an engineering context and that these six points should be considered as essential criteria on a checklist for determining if an activity is “authentic” PBL.

Inspired by the innovative approach being adopted in medical education, other disciplines started to adopt the PBL approach. An analysis of PBL in engineering conducted by an international panel, described by Kjersdam (1994), examined 20 years of the “Aalborg experiment” and found that half of graduates quoted the PBL work as the main source of relevant professional knowledge and concluded that the emphasis on synthesis and group culture produced a graduate more readily adaptable, and therefore employable, than the graduates of a more traditional education.

A later meta-analysis of medical education PBL, conducted by Dochy et al. (2003), found a robust positive influence of PBL on students’ ability to apply knowledge, but a negative tendency in so much that PBL students acquire slightly less knowledge than those on a traditional course, yet significantly retained more of this acquired knowledge. In a study examining the effectiveness of active learning in engineering education by Prince (2004), it was observed that there were many different approaches at different institutions, which made comparison difficult. Previous attempts to quantify the impact of PBL in medical education had typically looked at the effect size in relation to the mean performance of a population before and after an intervention. Within engineering education however, the variation among implementations led Prince (2004) to comment that no consistent results are likely to emerge from meta-studies as “the signal from the common elements of PBL would have to be greater than the noise produced by the differences in implementation of both PBL and the traditional curricula”.

Based on the premise that checklists are a simple yet effective means of ensuring that gross errors or oversights are avoided and that best practice is followed (Gawande, 2010), the objective of this paper is to develop a single-page checklist that practitioners of DBT projects could complete, either to assist when designing an experience, as part of self-evaluation of existing DBTs, or when writing a paper describing such projects as an addition to the knowledgebase for the CDIO community.

**RESEARCH APPROACH**

As stated, significant differences in implementation are typical of PBL at different locations. Such variety was also found to be prevalent among the published descriptions of Design-Build experiences in conference papers within the Knowledge Library on the CDIO Initiative’s website (www.cdio.org). In order to visualize and identify trends of current PBL-DBT practice, a narrative review methodology was used to compare these conference papers from the CDIO Knowledge Library. At the outset, it was recognized that this approach has known limitations, not least of which being the subjective nature of the “expert” interpretation of what has been written by the various authors of these papers. In this instance, the authors of this paper each have over 10 years’ experience of designing and delivering DBT projects in a CDIO based curriculum.
41 papers were found in the CDIO website archive using the search strings “Design Build Test” and “capstone”. Of these, 26 were selected for inclusion in the review (Appendix 1), with papers describing introductory courses and those with no build-element being excluded. In total, papers with contributors from 19 different institutions are represented in the study.

The purpose of the review was to quantify which CDIO syllabus items at the X.X.X level were described as learning outcome objectives in the description of the DBT activities. No attempt was made to judge how successful the implementations had been, simply whether their CDIO syllabus outcomes were included as objectives of the projects in their descriptions. Further limitations to this approach are recognized in so much that it is likely many of the papers’ descriptions do not fully cover all of the intended outcomes, as these may not have been the main focus of the papers. There will also be DBT activities taking place throughout the CDIO community, which have not been written up and presented as conference papers. Additionally, more experienced CDIO collaborators may well have progressed from “show and tell” type papers to something with more of an Engineering Education Research (EER) emphasis and might not have contributed papers on their practice in this area, which may well be excellent and could be a valuable resource for others.

FINDINGS FROM THE NARRATIVE REVIEW

The CDIO syllabus items most commonly described (n > 10) as learning objectives in the reviewed papers, as illustrated in figure 1, were:

- 2.1.1 Problem Identification and Formulation
- 2.2.3 Experimental Inquiry
- 2.4.3 Creative Thinking
- 2.4.7 Time and Resource Management
- 3.1.2 Team Operation
- 3.1.3 Team Growth and Evolution
- 3.2.3 Written Communication
- 3.2.6 Oral Presentation
- 4.4.1 The Design Process
- 4.4.3 Utilization of Knowledge in Design
- 4.4.4 Disciplinary Design

The other most recurring themes identified by the narrative review of papers, which did not map conveniently to CDIO syllabus items, were designated as DBT operational considerations. In descending order of frequency these were, facilitator skills, industry links, motivation, workspaces and competition. These are shown in Figure 2.

CHECKLIST DEVELOPMENT

A table of essential and desirable attributes of Design-Implement experiences is presented in Chapter 5 of the CDIO book (Crawley et al, 2007, p107) and is derived from the Andersson et al. (2005) paper. Together with the PBL essentials from the original definition for medical PBL at McMaster (Barrows, 1996), and the findings of the narrative review of DBT practice undertaken in this study, the authors have developed a new, more comprehensive checklist (Appendix 2) with 3 major sections:

A. PBL Essentials
B. CDIO Syllabus Learning Objectives
C. Operational Considerations

Table 1 shows how the Andersson et al. (2005) essential and desirable attributes have been remapped on to the relevant sections of the new CDIO-PBL-DBT checklist.

<table>
<thead>
<tr>
<th>Andersson et al. (2005) Essential Attributes</th>
<th>Checklist Remapping</th>
</tr>
</thead>
<tbody>
<tr>
<td>provide product or systems design and implementation skills</td>
<td>Syllabus 4.4.1-4, 4.5.2-5</td>
</tr>
<tr>
<td>include elements of conception, design, implementation and operation</td>
<td>Syllabus 2.4.3&amp;4, 4.3.1&amp;2, 4.4.1,3&amp;4, 4.5.2/3/4, 4.6.1</td>
</tr>
<tr>
<td>enable testing and evaluation during the operation phase</td>
<td>Syllabus 4.5.5, 4.6.4</td>
</tr>
<tr>
<td>focus on learning outcomes rather than the product to be designed</td>
<td>Operational consideration</td>
</tr>
<tr>
<td>provide many alternative number of paths to the solution</td>
<td>Operational consideration</td>
</tr>
<tr>
<td>be fully integrated with the curricular activities</td>
<td>PBL Essentials (CDIO Standard 3)</td>
</tr>
<tr>
<td>include adequate training in use of equipment</td>
<td>Operational consideration</td>
</tr>
<tr>
<td>provide all students with similar opportunities to develop their skills</td>
<td>Operational consideration</td>
</tr>
<tr>
<td>increase students' motivation for engineering</td>
<td>Operational consideration</td>
</tr>
<tr>
<td>reward students fairly for their contribution to the task</td>
<td>Operational consideration</td>
</tr>
</tbody>
</table>

**Andersson et al. (2005) Desirable Attributes**

<p>| | |</p>
<table>
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<tbody>
<tr>
<td>provide a platform for training of professional competencies</td>
<td>Operational consideration</td>
</tr>
<tr>
<td>reinforce disciplinary knowledge</td>
<td>Syllabus 4.4.3</td>
</tr>
<tr>
<td>be cross-disciplinary</td>
<td>Syllabus 4.4.5</td>
</tr>
<tr>
<td>develop teamwork and build community</td>
<td>Syllabus 3.1.2, 3.1.3</td>
</tr>
<tr>
<td>allow students to build and operate small, medium and large systems</td>
<td>Syllabus 4.3.1-4, 4.4.1-3, 4.5.5, 4.6.4</td>
</tr>
<tr>
<td>allow general prototype fabrication, test and redesign</td>
<td>Operational consideration, Syllabus 4.5.2, 4.5.5, 4.6.4</td>
</tr>
<tr>
<td>develop written, oral and graphical communication skills</td>
<td>Syllabus 3.2.3-6</td>
</tr>
</tbody>
</table>

The methodology defined by Andersson et al (2005) for designing DBT experiences in a CDIO context includes consideration of the level to which each of the CDIO syllabus learning outcomes are to be implemented. Items which are merely introduced (I) to the students need not be assessed, whereas items, which are either taught (T) or utilized (U) should be assessed. To preserve this practice a column in section B of the new checklist has been included into which one or more of the I,T,U letters should be entered.

It is intended that items in section A of the checklist (PBL Essentials) should be present in all CDIO-DBT experiences. Section C (Operational Considerations) should be treated as optional elements.

**DISCUSSION**

The CDIO Syllabus and Standards offer a framework which is somewhat unique among engineering education communities. They act as a shared set of objectives against which collaborators can self-assess and structure improvement of their degree pathways. In order to maximize the potential for the CDIO community to help and learn from each other, the *Proceedings of the 13th International CDIO Conference, University of Calgary, Calgary, Canada, June 18-22, 2017.*
version 1.0 checklist developed here is presented as a means both of self-assessment of DBT practice and also as a means of more conveniently comparing disparate DBT implementations. If all DBT related papers included a completed checklist as an appendix then it would be possible to catalog these so that they could be sorted and filtered.

Version 1.0 of the checklist presented herein includes a number of blank rows at the end of section B. This is in recognition that further CDIO syllabus learning outcomes might be part of other, as yet unpublished, implementations. As best practice develops it is proposed that the CDIO community could revise items in section B through collaboration at workshops or roundtable discussions at the annual conference, or as activities carried out by the regional groupings. Subsequent versions will be enhanced by future collaborative discussion.

Regular curricular self-assessment is a healthy activity and much like the rubrics for the CDIO Standards, the checklist should be considered for DBT review.

CONCLUSIONS

The CDIO Knowledge Library does not provide evidence of rigorous development of DBT experiences in line with CDIO methodology. The variety of DBT implementations and how they are reported was found to make comparisons of efficacy difficult. The lack of a consistent structure or direct reference to the CDIO syllabus meant that in order to process the information contained therein the authors had to resort to using a narrative analysis to make educated guesses of the practitioners’ intent. This methodology has inherent reliability issues, but does therefore also reinforce the need for a reliable and structured tool such as the checklist being proposed in this paper.

A version 1.0 DBT checklist has been developed, which is cognisant of PBL literature and which collates best practice guidelines and current practice.

The authors contend that in future this checklist should be used by those submitting PBL papers to CDIO conferences and that subsequently such papers should only be included in the CDIO archive if a checklist has been completed. This would further facilitate advancement in the understanding of the CDIO community and in progressing best practice in this area of curriculum delivery.

Authors of previously published work should also be encouraged to retrospectively review their papers and complete the checklist. This would facilitate the archive material to be better sorted and filtered by those seeking to conduct further research and development, or enhance their own teaching practice.
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BIOGRAPHICAL INFORMATION

**J Paul Hermon**, is a Senior Lecturer (Education) in the School of Mechanical and Aerospace Engineering at Queen’s University Belfast, and is Programme Director for the Product Design Engineering degrees there. A graduate Mechanical Engineer (MEng, QUB 1987), he worked as a process development engineer in the electronics manufacturing industry for both Lucas Industries and Digital Equipment Corporation. He also has 15 years’ experience as an engineering and product design consultant working across a broad range of industry sectors.

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<th>Year</th>
<th>Authors</th>
<th>Title</th>
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<tbody>
<tr>
<td>2002</td>
<td>Miller D.W. &amp; Brodeur D.R.</td>
<td>The CDIO Capstone Course: An Innovation in Undergraduate Systems Engineering Education</td>
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<td>2002</td>
<td>Brodeur D.R., Young P.W., Blair K.B.</td>
<td>Problem-Based Learning in Engineering Education</td>
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<td>2004</td>
<td>Malmqvist J., Young P.W., Hallstrom S., Kuttenkeulern J., Svensson T.</td>
<td>Lessons Learned from Design-Build-Test-Based Project Courses</td>
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<td>2005</td>
<td>Surgenor B., Mechefske C., Wyss, U., Peelow J.</td>
<td>Capstone Design - Experience with Industry Based Projects</td>
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<td>2005</td>
<td>Armstrong P.J., Kee R.J., Kenny R.G., Cunningham G.</td>
<td>A CDIO Approach to the Final Year Capstone Project</td>
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<td>2007</td>
<td>Evertsson M., Bankel J., Enelund M., Eriksson A., Lindstedt P., Raisanen C.</td>
<td>Design-Implement Experience from the 2nd Year Capstone Course &quot;Integrated Design and Manufacturing&quot;</td>
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<td>2010</td>
<td>Van der Loos H.F.M., Croft E.A., Hodgson A., Mikkelsen J., Winkelman P.</td>
<td>Strategies to Engage Capstone Design Course Sponsors in High-Priority, Client-Focused Projects</td>
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<td>2010</td>
<td>Ting K.E., Cheah S.M.</td>
<td>Assessment of CDIO Skills for Student Final Year (Capstone) Projects of Different Genres</td>
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<td>2011</td>
<td>Escudeiro N., Escudeiro P., Barata A., Lobo C., Duarte M., Costa A.</td>
<td>Developing Undergraduate Projects in Multinational Teams to Enhance Employability</td>
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<td>2011</td>
<td>Fai S.K.</td>
<td>An Observational Study of Infusing Design Thinking into the CDIO Framework</td>
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<td>2012</td>
<td>Hellborg G.</td>
<td>Experiences from Design-Build-Test (DBT) Projects in Lighting Design</td>
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<td>2012</td>
<td>Loc N.H. &amp; Trung P.Q.</td>
<td>Integrated Learning Experiences in the Machine Design Course to Assess the Achievement of Intended Learning Outcomes</td>
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<td>2014</td>
<td>Nguyen H.L., Pham C.B.</td>
<td>Integration of Design Problems and Projects into Courses for Manufacturing Engineering Program</td>
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<td>Developing and Applying Rubrics for Comprehensive Capstone Project Assessment</td>
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<td>Kulmala R., Luimula M., Roslof J.</td>
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<td>Truong V.T., Le B.N., Nguyen M.D., Nguyen T.M.</td>
<td>Assessing the Maturity of Teamwork Capabilities Through CDIO Projects</td>
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<td>2014</td>
<td>Gonzalez L</td>
<td>In Embry-Riddle the Capstone Project Brings Closure to Structures</td>
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<td>2016</td>
<td>Hermon J.P.</td>
<td>Enhancing the Manufacturing Knowledge of Undergraduate Engineering Students: A Case Study of a Design-Build-Test Challenge</td>
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<td>2016</td>
<td>Kontio E., Lakanmaa R.L.</td>
<td>Design-Build Experiences - ICU Game Capstone Project</td>
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APPENDIX 2 – CDIO-PBL-DBT Checklist v1.0

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<thead>
<tr>
<th>A. PBL Essentials</th>
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<tr>
<td>Learning is student centered</td>
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<tr>
<td>Learning occurs in small groups</td>
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<tr>
<td>Teachers are facilitators or guides</td>
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<tr>
<td>Problems form the organizing focus and stimulus for learning</td>
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<tr>
<td>Problems are the vehicle for the development of problem-solving skills</td>
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<td>New information is acquired through self-directed learning</td>
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<td>CDIO Standard 3 - Fully integrated with the curriculum</td>
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<tr>
<th>B. CDIO Syllabus Learning Objectives</th>
<th>I / T / U</th>
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<tbody>
<tr>
<td>2.1.1 Problem Identification and Formulation</td>
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<tr>
<td>2.2.3 Experimental Inquiry</td>
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<tr>
<td>2.4.3 Creative Thinking</td>
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<td>2.4.4 Critical Thinking</td>
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<tr>
<td>2.4.7 Time and Resource Management</td>
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<tr>
<td>3.1.2 Team Operation</td>
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<td>3.1.3 Team Growth and Evolution</td>
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<td>3.2.3 Written Communication</td>
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<td>3.2.4 Electronic/Multimedia Communication</td>
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<td>3.2.5 Graphical Communications</td>
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<td>3.2.6 Oral Presentation</td>
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<td>4.3.1 Understanding Needs and Setting Goals</td>
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<td>4.3.2 Defining Function, Concept and Architecture</td>
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<tr>
<td>4.3.3 System Engineering, Modeling and Interfaces</td>
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<td>4.3.4 Development Project Management</td>
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<tr>
<td>4.4.1 The Design Process</td>
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<td>4.4.2 The Design Process Phasing and Approaches</td>
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<tr>
<td>4.4.3 Utilization of Knowledge in Design</td>
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<td>4.4.4 Disciplinary Design</td>
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<td>4.4.5 Multidisciplinary Design</td>
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<td>4.5.2 Hardware Manufacturing Process</td>
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<td>4.5.3 Software Implementing Process</td>
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<td>4.5.4 Hardware Software Integration</td>
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<td>4.5.5 Test, Verification, Validation and Certification</td>
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<tr>
<td>4.6.1 Designing and Optimizing Sustainable and Safe Operations</td>
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<tr>
<td>4.6.4 System Improvement and Evolution</td>
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<thead>
<tr>
<th>C. Operational Considerations</th>
<th>✓</th>
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<tr>
<td>CDIO Standard 10 – Enhancement of faculty teaching competence (facilitator / mentor)</td>
<td></td>
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<tr>
<td>Assessment focus on learning outcomes rather than the product to be designed</td>
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<tr>
<td>Assessment should reward students fairly for their contribution to the task</td>
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<tr>
<td>Provide alternative paths to the solution (open ended problem)</td>
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<tr>
<td>Provide adequate workspaces for building and testing</td>
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<tr>
<td>Include adequate training in use of equipment</td>
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<tr>
<td>Increase students' motivation for engineering (through industry links / competition)</td>
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<tr>
<td>Provide students with learning and assessment opportunities suited to a range learning style preferences</td>
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<tr>
<td>Provide students with a platform for development of professional skills</td>
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<tr>
<td>Timeframe which enables prototype fabrication, test and redesign</td>
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A SELF-EFFICACY SURVEY FOR ENGINEERING GRADUATE ATTRIBUTES ASSESSMENT

Robert W. Brennan, Ronald J. Hugo
Schulich School of Engineering, University of Calgary

ABSTRACT

In this paper, we describe a self-efficacy survey that was developed as part of the graduate attributes assessment and continual improvement process for a Canadian undergraduate engineering program. The aim of this study is twofold: first, to evaluate the reliability of the self-efficacy survey in the context of the graduate attributes; second, to compare the trends in student self-efficacy over multiple years. The survey results, reported from a six-year study of a BSc in Mechanical Engineering program, point to two main conclusions: (1) the self-efficacy survey appears to be a reliable tool for graduate attributes assessment, and (2) students report higher levels of self-efficacy for professional or “soft skills” attributes than for technical attributes; although somewhat counter-intuitive, these results are consistent with the literature on the achievement of mastery given the timing and context of the survey in the students’ program.

KEYWORDS

Student assessment; self-efficacy; accreditation; design education; continual improvement.

This paper reports on a CDIO-inspired assessment tool (Standard 12).

INTRODUCTION

In this paper, we report on a self-efficacy survey that was developed by the authors for use in the Schulich School of Engineering’s continual improvement process. Self-efficacy is defined as “the belief in one’s capabilities to organize and execute the courses of action required to manage prospective situations” (Bandura, 1995). This belief in one’s abilities is typically developed through “mastery experiences” (Bandura, 1994). For example, in the context of engineering design, Carberry et al. (2010) note that “the effect of self-efficacy on learning can be more pronounced because of the frequent uses of design tasks as part of an engineering learning experience”; they go on to show that student motivation towards engineering design relates to higher levels of self-efficacy. More recently, Mamaril et al. (2016) showed that their engineering self-efficacy scales can be reliably used to assess undergraduate students’ perceptions of their capabilities in engineering.

Given this link between student self-efficacy and “mastery experiences” in engineering learning, it follows that self-efficacy can serve as a useful measure of whether or not a course has provided an authentic engineering experience for students, and in particular, if the course is successfully motivating students to learn.

The self-efficacy survey used for this study focuses on the Canadian Engineering Accreditation Board’s (CEAB) twelve graduate attributes (CEAB, 2015):

1. A knowledge base for engineering
2. Problem analysis
3. Investigation
4. Design
5. Use of engineering tools
6. Individual and team work
7. Communication skills
8. Professionalism
9. Impact of engineering on society
10. Ethics and equity
11. Economics & project management
12. Life-long learning

Under these criteria, Canadian engineering programs are required to assess student graduate attributes in these twelve general areas, and demonstrate that a process is being followed to continuously improve the programs. In order to demonstrate that graduates of an engineering program possess these general attributes, each graduate attribute was expanded into a set of indicators that “describe specific abilities expected of students to demonstrate each attribute” (CEAB, 2015). In addition to providing a means of obtaining evidence to determine if the attribute has been achieved, the indicators had to be acceptable within the context of the program’s educational objectives, as well as understood and meaningful to those involved in the assessments (e.g., faculty, students, alumni).

The self-efficacy survey reported in this paper is one of a set of measurement tools that are being used for graduate attributes assessment at the Schulich School of Engineering. The idea is to provide multiple forms of evidence for each attribute (i.e., classroom assessments, student surveys, employer surveys) in order to increase the reliability of our graduate attribute assessment process. In this paper, we report on the student survey aspect of the process, where students are asked to indicate how confident they are in their ability, at the time of the survey, to perform a variety of activities related to the CEAB’s twelve graduate attributes.

In this paper, we provide an overview of the self-efficacy survey and reflect on our experience with the survey in the context of graduate attributes assessment over a six-year period. We report on the internal consistency of the survey questions, and evaluate student self-efficacy across multiple years of the BSc in Mechanical Engineering program.

**AIM OF THE STUDY**

The aim of this study is twofold: first, to evaluate the reliability of the self-efficacy survey in the context of the twelve CEAB graduate attributes. In order to keep the survey to a reasonable length (in this case, 38 questions), each graduate attribute was associated with 3 to 4 survey questions. Despite the relatively small number of questions associated with each graduate attribute, there should be internal consistency within each of the categories (graduate attributes) of survey: i.e., the responses to each of the questions within a graduate attribute category should point in the same direction. The second aim is to compare the trends in student self-efficacy over multiple years, in a single course (a fourth-year, capstone design course). As noted, self-efficacy is related to a belief in one’s capabilities and is typically reinforced through learning experiences. Comparing self-efficacy scores over multiple years of a single program can provide a means of identifying potential gaps in students’ learning experience.
METHODS

Participants

Our study was conducted with senior (fourth year) B.Sc. in Mechanical Engineering students near the end of their program. More specifically, the self-efficacy survey was conducted late in the final term in the compulsory, senior capstone design course. The BSc in Mechanical Engineering capstone design course runs for two terms (from the start of the Fall term to the end of the Winter term). Students are placed in teams of four to five that work on an industry- or faculty-sponsored design project. These capstone projects involve the student team in the entire product design process from identifying customer needs, through conceptual and detailed design, to design validation (e.g., building prototypes). Course instruction occurs primarily during the first term, and focuses on the product development process (Ulrich and Eppinger, 2015), project management, economics, communication, and teamwork; the second term is dedicated entirely to student work on the design projects.

Altogether, 271 Canadian engineering students (aged mean ± standard deviation = 22.7 ± 1.2, range = 18-25 years) out of which 53 were females and 218 were males participated in this study. As noted, the students were in the final term of their final year of study. The survey was administered over 5 offerings of the mechanical engineering capstone design course from Winter term 2011 and to Winter term 2016 (no data was collected for Winter 2015). The total number of potential participants was 789 students, resulting in a 34% participation rate in the study.

The Survey

The self-efficacy survey was developed by the authors in 2010 to support graduate attributes collection for accreditation and continual improvement purposes at the Schulich School of Engineering. The survey includes 38 questions that are posed in the form of “how confident are you in your current ability to …”; students are required to rate their confidence on a five-interval scale ranging from 0% “no confidence” to 100% “total confidence” (in 25% intervals).

Each graduate attribute was associated with 3 to 4 survey questions, that were developed using the CDIO syllabus (Crawley et al., 2007) and its corresponding mapping to the CEAB graduate attributes (Cloutier et al., 2010) as a starting point. For example, the survey questions associated with graduate attribute 3.1.4 “design” are:

How confident are you in your ability to:

• collect and interpret customer needs for a project you were given.
• analyze the trade-offs between alternative design approaches and select the one that is best for your project.
• test a design solution to determine if it meets its specified needs.
• The full set of survey questions are provided in the appendix.

The survey was administered on a voluntary basis to five cohorts of final-year mechanical engineering students from Winter term 2011 to Winter term 2016. When introducing the survey to the class near the end of their final term, it was described as a “survey on engineering competencies developed to date”: responses should reflect students’ belief in
their ability to succeed in the specific situations described in the survey. The survey was administered online using the Survey Monkey tool. Although this provided students flexibility with respect to when and where the survey could be completed, administering the survey online resulted in the relatively low participation rate of 37%.

**Statistical Analysis**

As noted previously, one of the main aims of this study is to evaluate the reliability of the self-efficacy survey in the context of the twelve CEAB graduate attributes. To evaluate the reliability of the survey, Cronbach’s alpha coefficients were computed over the full set of data. More specifically, we use Cronbach’s alpha to measure the internal consistency for each graduate attribute based on the correlations between each of the survey questions in each graduate attribute grouping. “Internal consistency” describes the extent to which all the items in a test measure the same concept or construct (Tavokol and Dennick, 2011). For our purposes, we are interested in the inter-relatedness of the questions within each graduate attribute grouping. Cronbach’s alpha reliability coefficient ranges from 0 to 1. The basic rules of thumb for this coefficient are: “≥0.9 → excellent, ≥0.8 → good, ≥0.7 → acceptable, ≥0.6 → questionable, ≥0.5 → poor, and <0.5 → unacceptable” (George and Mallery, 2003).

The amount of data obtained over five offerings of the mechanical engineering capstone design course also provided us with the opportunity to compare the trends in student self-efficacy across multiple years. For this analysis, paired samples t-test and ANOVA were used to determine if there are any differences in student self-efficacy between graduate attribute, between genders, and between student cohorts.

As noted, students completed the survey on a voluntary basis. In the vast majority of cases, students completed the entire survey; however, any instances of incomplete surveys were treated as outliers and were removed from the data set.

**RESULTS**

**Reliability of the Survey**

Table 1 provides a summary of student self-efficacy towards the twelve CEAB graduate attributes for all five mechanical engineering capstone design cohorts.

<table>
<thead>
<tr>
<th>Graduate Attribute</th>
<th>Mean</th>
<th>s</th>
<th>Cronbach’s alpha if item deleted</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. A knowledge-base for engineering Item-total statistics; Cronbach's alpha = 0.73</td>
<td>0.77</td>
<td>0.22</td>
<td>0.58</td>
</tr>
<tr>
<td>Q10. Use your technical knowledge to participate in a design discussion.</td>
<td>0.62</td>
<td>0.27</td>
<td>0.73</td>
</tr>
<tr>
<td>Q11. Describe a well-known experiment that proved an important scientific law.</td>
<td>0.80</td>
<td>0.20</td>
<td>0.57</td>
</tr>
<tr>
<td>Q20. Use mathematics to describe and solve engineering problems.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Internal Consistency of the Self-efficacy Survey (continued)

<table>
<thead>
<tr>
<th>Graduate Attribute</th>
<th>Mean</th>
<th>s</th>
<th>Cronbach’s alpha if item deleted</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2. Problem analysis</strong></td>
<td></td>
<td></td>
<td>Item-total statistics; Cronbach’s alpha = 0.75</td>
</tr>
<tr>
<td>Q1. Apply your engineering knowledge and skills to solve a real-world problem.</td>
<td>0.75</td>
<td>0.20</td>
<td>0.71</td>
</tr>
<tr>
<td>Q16. Make assumptions that successfully simplify a complex problem to make it easier to work with.</td>
<td>0.74</td>
<td>0.21</td>
<td>0.67</td>
</tr>
<tr>
<td>Q21. After solving a problem, evaluate your initial assumptions to see if they need to be changed.</td>
<td>0.76</td>
<td>0.18</td>
<td>0.63</td>
</tr>
<tr>
<td><strong>3. Investigation</strong></td>
<td></td>
<td></td>
<td>Item-total statistics; Cronbach’s alpha = 0.75</td>
</tr>
<tr>
<td>Q7. Generate a working hypothesis and a strategy to test it.</td>
<td>0.74</td>
<td>0.20</td>
<td>0.79</td>
</tr>
<tr>
<td>Q13. Synthesize information to reach conclusions that are supported by data and needs.</td>
<td>0.78</td>
<td>0.18</td>
<td>0.62</td>
</tr>
<tr>
<td>Q14. Analyze and interpret data.</td>
<td>0.83</td>
<td>0.19</td>
<td>0.57</td>
</tr>
<tr>
<td><strong>4. Design</strong></td>
<td></td>
<td></td>
<td>Item-total statistics; Cronbach’s alpha = 0.80</td>
</tr>
<tr>
<td>Q24. Test a design solution to determine if it meets its specified needs.</td>
<td>0.77</td>
<td>0.19</td>
<td>0.81</td>
</tr>
<tr>
<td>Q28. Collect and interpret customer needs for a project you were given.</td>
<td>0.81</td>
<td>0.19</td>
<td>0.67</td>
</tr>
<tr>
<td>Q29. Analyze the trade-offs between alternative design approaches and select the one that is best for your project.</td>
<td>0.81</td>
<td>0.18</td>
<td>0.68</td>
</tr>
<tr>
<td><strong>5. Use of engineering tools</strong></td>
<td></td>
<td></td>
<td>Item-total statistics; Cronbach’s alpha = 0.79</td>
</tr>
<tr>
<td>Q2. Apply an appropriate engineering technique or tool to accomplish a task.</td>
<td>0.76</td>
<td>0.18</td>
<td>0.69</td>
</tr>
<tr>
<td>Q6. Adapt or extend an engineering technique to accomplish a complex task.</td>
<td>0.72</td>
<td>0.21</td>
<td>0.65</td>
</tr>
<tr>
<td>Q25. Describe the limitations of various engineering tools and choose the best one to accomplish a task.</td>
<td>0.71</td>
<td>0.20</td>
<td>0.80</td>
</tr>
<tr>
<td><strong>6. Individual and team work</strong></td>
<td></td>
<td></td>
<td>Item-total statistics; Cronbach’s alpha = 0.74</td>
</tr>
<tr>
<td>Q3. Get team members to make personal commitments to deliver what they had agreed to do for a project.</td>
<td>0.79</td>
<td>0.19</td>
<td>0.68</td>
</tr>
<tr>
<td>Q8. Review your team’s strengths and weaknesses and tell others where the team might need help.</td>
<td>0.78</td>
<td>0.19</td>
<td>0.66</td>
</tr>
<tr>
<td>Q12. Help two project team members with a strong disagreement resolve their differences.</td>
<td>0.71</td>
<td>0.21</td>
<td>0.69</td>
</tr>
<tr>
<td>Q35. At the start of a project, identify all the roles and responsibilities that your team will need to complete it.</td>
<td>0.75</td>
<td>0.20</td>
<td>0.70</td>
</tr>
</tbody>
</table>

*Proceedings of the 13th International CDIO Conference, University of Calgary, Calgary, Canada, June 18-22, 2017.*
Table 1. Internal Consistency of the Self-efficacy Survey (continued)

<table>
<thead>
<tr>
<th>Graduate Attribute</th>
<th>Mean</th>
<th>s</th>
<th>Cronbach’s alpha if item deleted</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. Communication skills Item-total statistics; Cronbach's alpha = 0.72</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q19. Deliver a clear and organized formal presentation to a group of professionals.</td>
<td>0.84</td>
<td>0.20</td>
<td>0.66</td>
</tr>
<tr>
<td>Q22. Interpret a formal technical drawing in your engineering discipline.</td>
<td>0.74</td>
<td>0.25</td>
<td>0.67</td>
</tr>
<tr>
<td>Q26. Use various written styles to communicate complex engineering concepts to your colleagues.</td>
<td>0.77</td>
<td>0.22</td>
<td>0.63</td>
</tr>
<tr>
<td>Q30. Prepare a sketch of a design concept that is understood by your colleagues.</td>
<td>0.76</td>
<td>0.25</td>
<td>0.65</td>
</tr>
<tr>
<td>8. Professionalism Item-total statistics; Cronbach's alpha = 0.71</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q9. Identify processes in your project to ensure protection of the public and the public interest.</td>
<td>0.76</td>
<td>0.19</td>
<td>0.54</td>
</tr>
<tr>
<td>Q15. Identify the regulatory policies that pertain to a project that you are working on.</td>
<td>0.67</td>
<td>0.24</td>
<td>0.67</td>
</tr>
<tr>
<td>Q38. Identify your professional responsibilities within a large engineering project.</td>
<td>0.81</td>
<td>0.19</td>
<td>0.65</td>
</tr>
<tr>
<td>9. Impact of engineering on society and the environment Item-total statistics; Cronbach's alpha = 0.69</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q4. Identify the interactions that an engineering project has with the economic, social, health, safety, legal, &amp; cultural aspects of society.</td>
<td>0.78</td>
<td>0.19</td>
<td>0.66</td>
</tr>
<tr>
<td>Q27. Apply technical, social, and environmental criteria to guide trade-offs between design alternatives.</td>
<td>0.76</td>
<td>0.20</td>
<td>0.47</td>
</tr>
<tr>
<td>Q34. Incorporate sustainability considerations in project decision-making.</td>
<td>0.72</td>
<td>0.23</td>
<td>0.65</td>
</tr>
<tr>
<td>10. Ethics and equity Item-total statistics; Cronbach's alpha = 0.69</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q18. Admit when you have made a mistake.</td>
<td>0.90</td>
<td>0.18</td>
<td>0.80</td>
</tr>
<tr>
<td>Q36. Identify an ethical dilemma when it occurs in a project.</td>
<td>0.81</td>
<td>0.20</td>
<td>0.48</td>
</tr>
<tr>
<td>Q37. Analyze opposing positions on an issue and make a judgment based on the evidence.</td>
<td>0.82</td>
<td>0.17</td>
<td>0.46</td>
</tr>
<tr>
<td>11. Economics and project management Item-total statistics; Cronbach's alpha = 0.71</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q17. Apply project cost management principles to ensure that a project is completed within budget.</td>
<td>0.70</td>
<td>0.25</td>
<td>0.64</td>
</tr>
<tr>
<td>Q31. Identify and plan for risks in an engineering project.</td>
<td>0.72</td>
<td>0.21</td>
<td>0.52</td>
</tr>
<tr>
<td>Q33. Work with others to establish project objectives when different project tasks must be completed.</td>
<td>0.82</td>
<td>0.18</td>
<td>0.67</td>
</tr>
</tbody>
</table>
Table 1. Internal Consistency of the Self-efficacy Survey (continued)

<table>
<thead>
<tr>
<th>Graduate Attribute</th>
<th>Mean</th>
<th>s</th>
<th>Cronbach's alpha if item deleted</th>
</tr>
</thead>
<tbody>
<tr>
<td>12. Life-long learning</td>
<td>0.85</td>
<td>0.16</td>
<td>0.59</td>
</tr>
<tr>
<td>Q5. Recognize your strengths and weaknesses when working on a specific problem.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q23. Identify the best approach that is suited to your learning style.</td>
<td>0.81</td>
<td>0.19</td>
<td>0.42</td>
</tr>
<tr>
<td>Q32. Use technical literature or other information sources to fill a gap in your knowledge.</td>
<td>0.81</td>
<td>0.20</td>
<td>0.58</td>
</tr>
</tbody>
</table>

As shown in this table, the self-efficacy survey was found to be acceptable for all graduate attributes except graduate attribute 12 “life-long learning” (α = 0.63), which was questionable. For the majority of the graduate attributes, it appears that the three to four questions identified in the survey are needed to maintain internal consistency; however, for graduate attribute 3 “investigation” and 10 “ethics and equity”, internal consistency would be improved if one question were removed. In these cases, Q7 (α for 3.1.3 changes from 0.75 to 0.79) and Q18 (α for 3.1.10 changes from 0.69 to 0.80) should be re-evaluated in the context of the CEAB/CDIO mapping (Cloutier et al., 2010) in order to improve the overall reliability of the survey for these graduate attributes. As well, the three questions associated with 3.1.12 “life-long learning” will need to revisited.

Self-efficacy Trends

The average self-efficacy scores with 95% confidence intervals for the period from 2011 to 2016 are shown in Figure 1.

As can be seen in this figure, the top three self-efficacy scores are reported for graduate attributes 4 “design”, 10 “ethics and equity”, and 12 “life-long learning”; the bottom three self-efficacy scores are reported for graduate attributes 1 “a knowledge-base for engineering”, 2 “problem analysis”, and 5 “use of engineering tools”. The results of a one-way ANOVA test showed that this difference between the top three and the bottom three graduate attributes is significant, $F(11, 251) = 12.19, p < 0.01$: i.e., graduate attributes 4 ($M = 79.6\%, SD = 15.8\%$), graduate attribute 10 ($M = 83.9\%, SD = 12.2\%$), and graduate attribute 12 ($M = 82.1\%, SD = 13.8\%$) reported significantly higher self-efficacy scores than graduate attributes 1 ($M = 73.0\%, SD = 18.5\%$), graduate attribute 2 ($M = 74.7\%, SD = 16.1\%$), and graduate attribute 5 ($M = 73.0\%, SD = 16.5\%$).

In order to determine if there were any differences between male and female engineering students’ perceptions of their abilities with respect to the twelve graduate attributes, we performed a paired-samples t-test using the five years of data. The results showed that self-efficacy for male students was significantly higher than that of female students for graduate attributes 2 “problem analysis” ($\Delta M = -9.4\%, t(48) = -2.96, p < 0.05$) and graduate attribute 5 “use of engineering tools” ($\Delta M = -9.5\%, t(48) = -2.90, p < 0.05$). Although the self-efficacy...
scores for males were higher than those for females for all graduate attributes except graduate attribute 10 “ethics and equity” (ΔM = 1.7%, t(48) = 0.72, p = n.s.), only graduate attributes 2 and 5 were significant at the p < 0.05 level. Given this trend in the results and the relatively small proportion of female students (20% of the population), it would be interesting to extend this study to a larger sample size to further explore the differences between male and female self-efficacy.

As can be seen from the list of CEAB graduate attributes at the beginning of this paper, the twelve graduate attributes are effectively divided in two categories: a group of six “technical” attributes (graduate attributes 1-5 and 11) and six “soft-skills” or “professional” attributes (graduate attributes 6-10 and 12). In order to explore differences between these more general categories, the data was aggregated in this manner. The results of a paired samples t-test showed that student self-efficacy for the technical graduate attributes (M = 75.6%, SD = 14.1%) was significantly lower than student self-efficacy for the professional skills graduate attributes (M = 78.1%, SD = 11.9%), t(250) = -5.38, p < 0.01. Comparing male and female students across the technical and professional attributes categories revealed a statistically significant difference for only the technical graduate attributes: male students (M = 76.7%, SD = 14.0%) showed significantly higher technical attributes self-efficacy than female students (M = 71.2%, SD = 13.4%), t(250) = 15.7, p < 0.05.

Finally, self-efficacy scores were also compared across student cohorts (i.e., across each year from 2011 to 2016). The one-way ANOVA results showed no significant difference from
cohort-to-cohort. This is not surprising given that there were no major changes to the B.Sc. in mechanical engineering curriculum or admission process during this period of time.

**DISCUSSION**

Given the relatively high proportion of time dedicated to technical topics in most undergraduate engineering programs, the results of the self-efficacy survey at first seem counter-intuitive. The Schulich School of Engineering’s BSc in Mechanical Engineering program does not differ from other undergraduate engineering programs in this regard: approximately 90% of the program’s curriculum content is in the form of technical courses (i.e., mathematics, natural sciences, engineering sciences, design). It should be noted that this is not surprising, given that the CEAB’s minimum curriculum content criteria require 85% of a program’s curriculum to be in these technical areas. However, the results of the self-efficacy survey indicate that students’ expectations of personal efficacy in technical areas are lower than their expectations of personal efficacy in professional or “soft-skills” areas.

To understand these results, it is important to look at the survey in the context of where and when it was administered, and also at the nature of self-efficacy. As noted previously, the self-efficacy survey was administered during the final term of students’ program in their capstone design course. At this point in the BSc in Mechanical Engineering program, students would not lack component technical skills in mechanical engineering, and arguably, would be relatively comfortable with integrating these skills to solve complex engineering problems. However, they will have had little experience transferring these technical skills from the very “academic” and compartmentalized context of the engineering and science courses from the past seven terms, to the open-ended and team-based context of a complex design problem. In other words, they are now confronted with an open-ended technical problem that does not have a single “correct” answer, requires some degree of “trial-and-error” to solve, and is too complex to be managed by one individual; a very different prospect from the problems and projects encountered in engineering and science courses encountered up to this point in their programs.

One’s expectations of personal efficacy are closely related to mastery experiences. As Bandura (1994) notes, “successes build a belief in one’s efficacy. Failures undermine it.” However, by nature, the engineering design process is iterative and requires one to “embrace failure” (Kelley and Kelley, 2013). As a result, students’ recognition of the limitations of their technical skills during their first major design project should not come as a surprise. In fact, it is promising that students do recognize these limitations: at this point in their progression from novice students to professional engineers, they have advanced to a stage of “conscious competence” where they are “… increasingly aware of what they do not know, and consequently, of what they need to learn” (Ambrose et al., 2010). In this regard, it is also not surprising that students are also confident with their “life-long learning” abilities.

Although it is encouraging that the self-efficacy survey appears to be a reliable assessment tool, more work is required: as noted, our future work on the survey will involve refining questions where internal consistency is in question. In particular, more work is needed on refining the questions associated with graduate attribute 3 “investigation”, graduate attribute 10 “ethics and equity”, and graduate attribute 12 “life-long learning”. As with our early work
on the survey, we plan to use the CDIO syllabus (Crawley et al., 2007) as a starting point for this work.

Our future work in this area will also involve analyzing the self-efficacy survey results in the context of the other assessments (e.g., classroom assessments, employer surveys). As was shown in this paper, the nature of self-efficacy assessment can lead to what at first appears to be counter-intuitive results. However, it is our belief that much can be learned about the teaching and learning environment from this additional form of student assessment.

REFERENCES


BIOGRAPHICAL INFORMATION

Robert W. 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.

Ronald J. Hugo is Professor of Mechanical and Manufacturing Engineering and Associate Dean (Teaching & Learning) at the University of Calgary. He is also the holder of the Engineering Education Innovation Chair in the Schulich School of Engineering. His research interests are in the areas of experimental fluid dynamics, energy systems, and engineering education.

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APPENDIX

The following table lists the 38 questions used in the spring 2011 self-efficacy survey. The survey questions are sorted by graduate attribute with the actual question order shown in column 2 under “survey question”.

<table>
<thead>
<tr>
<th>Graduate Attribute</th>
<th>Survey Question</th>
<th>How confident are you in your current ability to:</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1.1</td>
<td>10</td>
<td>Use your technical knowledge to participate in a design discussion.</td>
</tr>
<tr>
<td>3.1.1</td>
<td>11</td>
<td>Describe a well-known experiment that proved an important scientific law.</td>
</tr>
<tr>
<td>3.1.1</td>
<td>20</td>
<td>Use mathematics to describe and solve engineering problems.</td>
</tr>
<tr>
<td>3.1.2</td>
<td>1</td>
<td>Apply your engineering knowledge and skills to solve a real-world problem.</td>
</tr>
<tr>
<td>3.1.2</td>
<td>16</td>
<td>Make assumptions that successfully simplify a complex problem to make it easier to work with.</td>
</tr>
<tr>
<td>3.1.2</td>
<td>21</td>
<td>After solving a problem, evaluate your initial assumptions to see if they need to be changed.</td>
</tr>
<tr>
<td>3.1.3</td>
<td>7</td>
<td>Generate a working hypothesis and a strategy to test it.</td>
</tr>
<tr>
<td>3.1.3</td>
<td>13</td>
<td>Synthesize information to reach conclusions that are supported by data and needs.</td>
</tr>
<tr>
<td>3.1.3</td>
<td>14</td>
<td>Analyze and interpret data.</td>
</tr>
<tr>
<td>3.1.4</td>
<td>24</td>
<td>Test a design solution to determine if it meets its specified needs.</td>
</tr>
<tr>
<td>3.1.4</td>
<td>28</td>
<td>Collect and interpret customer needs for a project you were given.</td>
</tr>
<tr>
<td>3.1.4</td>
<td>29</td>
<td>Analyze the trade-offs between alternative design approaches and select the one that is best for your project.</td>
</tr>
<tr>
<td>3.1.5</td>
<td>2</td>
<td>Apply an appropriate engineering technique or tool to accomplish a task.</td>
</tr>
<tr>
<td>3.1.5</td>
<td>6</td>
<td>Adapt or extend an engineering technique to accomplish a complex task.</td>
</tr>
<tr>
<td>3.1.5</td>
<td>25</td>
<td>Describe the limitations of various engineering tools and choose the best one to accomplish a task.</td>
</tr>
<tr>
<td>3.1.6</td>
<td>3</td>
<td>Get team members to make personal commitments to deliver what they had agreed to do for a project.</td>
</tr>
<tr>
<td>3.1.6</td>
<td>8</td>
<td>Review your team’s strengths and weaknesses and tell others where the team might need help.</td>
</tr>
<tr>
<td>3.1.6</td>
<td>12</td>
<td>Help two project team members with a strong and emotional disagreement resolve their differences.</td>
</tr>
<tr>
<td>3.1.6</td>
<td>35</td>
<td>At the start of a project, identify all the roles and responsibilities that your team will need to complete it.</td>
</tr>
<tr>
<td>3.1.7</td>
<td>19</td>
<td>Deliver a clear and organized formal presentation to a group of professionals.</td>
</tr>
<tr>
<td>3.1.7</td>
<td>22</td>
<td>Interpret a formal technical drawing in your engineering discipline.</td>
</tr>
<tr>
<td>3.1.7</td>
<td>26</td>
<td>Use various written styles to communicate complex engineering concepts to your colleagues.</td>
</tr>
<tr>
<td>3.1.7</td>
<td>30</td>
<td>Prepare a sketch of a design concept that is understood by your colleagues.</td>
</tr>
<tr>
<td>3.1.8</td>
<td>9</td>
<td>Identify processes in your project to ensure protection of the public and the public interest.</td>
</tr>
<tr>
<td>3.1.8</td>
<td>15</td>
<td>Identify the regulatory policies that pertain to a project that you are working on.</td>
</tr>
<tr>
<td>Graduate Attribute</td>
<td>Survey Question</td>
<td>How confident are you in your current ability to:</td>
</tr>
<tr>
<td>--------------------</td>
<td>----------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>3.1.8</td>
<td>38</td>
<td>Identify your professional responsibilities within a large engineering project.</td>
</tr>
<tr>
<td>3.1.9</td>
<td>4</td>
<td>Identify the interactions that an engineering project has with the economic, social, health, safety, legal, and cultural aspects of society.</td>
</tr>
<tr>
<td>3.1.9</td>
<td>27</td>
<td>Apply technical, social, and environmental criteria to guide trade-offs between design alternatives.</td>
</tr>
<tr>
<td>3.1.9</td>
<td>34</td>
<td>Incorporate sustainability considerations in project decision-making.</td>
</tr>
<tr>
<td>3.1.10</td>
<td>18</td>
<td>Admit when you have made a mistake.</td>
</tr>
<tr>
<td>3.1.10</td>
<td>36</td>
<td>Identify an ethical dilemma when it occurs in a project.</td>
</tr>
<tr>
<td>3.1.10</td>
<td>37</td>
<td>Analyze opposing positions on an issue and make a judgment based on the evidence.</td>
</tr>
<tr>
<td>3.1.11</td>
<td>17</td>
<td>Apply project cost management principles to ensure that a project is completed within budget.</td>
</tr>
<tr>
<td>3.1.11</td>
<td>31</td>
<td>Identify and plan for risks in an engineering project.</td>
</tr>
<tr>
<td>3.1.11</td>
<td>33</td>
<td>Work with others to establish project objectives when different project tasks must be completed.</td>
</tr>
<tr>
<td>3.1.12</td>
<td>5</td>
<td>Recognize your strengths and weaknesses when working on a specific problem.</td>
</tr>
<tr>
<td>3.1.12</td>
<td>23</td>
<td>Identify the best approach that is suited to your learning style.</td>
</tr>
<tr>
<td>3.1.12</td>
<td>32</td>
<td>Use technical literature or other information sources to fill a gap in your knowledge.</td>
</tr>
</tbody>
</table>
STUDENTS PERSPECTIVES ON VIDEO-BASED LEARNING IN CDIO-BASED PROJECT COURSES

Kanishk Bhadani, Christian Stöhr, Erik Hulthén, Johannes Quist, Magnus Bengtsson, Magnus Evertsson, Johan Malmqvist
Chalmers University of Technology

ABSTRACT

This paper aims at demonstrating the applicability of video learning in CDIO-based project courses and at evaluating to what extent it benefits students. The courses are Machine Elements (PPU210), Product Planning - Needs and Opportunities (PPU085) and Engineering Design and Optimization (PPU190) in the Mechanical Engineering programme at Chalmers University of Technology. The research was carried out by first creating a set of videos for selected topics in three courses. In total, 22 videos were created including topics such as “Benchmarking”, “SWOT”, and “Prototype lab equipment instructions”. The learning outcomes of the video lectures were mapped to the CDIO syllabus. A blended learning environment was developed, i.e. the videos were utilized as additional support alongside existing learning activities. The videos were then used in the courses and the students’ feedbacks collected through a dedicated questionnaire, the regular course evaluation survey, and in student-teacher group meetings during and after the courses. The collected data was analysed to produce inferences about the applicability and utility of the video lectures.

The resulting analysis shows the students’ preferences regarding the evaluated video lectures and instructions. The students find videos more appealing compared to traditional lectures. One of the main benefits highlighted is the possibility of watching the videos in parallel to the design-build-test project execution rather having the classroom lecture only. This helps in reinforcing concepts, and results in less dependency on supervisors during the project execution. Videos proved to be suitable for creating a blended learning environment and improved the perceived learning experience for the students. In order to maximize student satisfaction and interaction with the videos, the videos should be short and closely aligned to the other learning activities. The paper also suggests future improvements to be carried out for video-based learning in the courses, and proposes an easy adaptable way for teachers to develop video material.

KEYWORDS

CDIO Standards 2, 5, 7, 8; Video-based learning, Design-build-test project, Blended Learning, STEM education, Problem-based learning
INTRODUCTION

It has been observed recently that the advancements in information technology and digitalization, along with the increased affordability of educational technology, has led to a broader adoption of those technologies in higher education. At the same time, student behaviour towards learning is changing and many students prefer student-driven personalized learning, which is typically enabled by an availability of online resources (Chen, 2008; Cronhjort & Weurlander, 2016). This gives students more flexibility and control over their learning process.

There are many examples of successful applications of video-based learning (VBL) in engineering and science education, e.g., in software and control theory (Cabezuelo et al., 2015) or physics (Stöhr et al., 2016). However, there are comparably fewer examples of video-based learning in design-build-test project courses. Reasons for this may include that design education often relies on personal tutoring and feedback in small-group settings as well as the wish and need to build things as learning experiences.

The Mechanical Engineering programme at Chalmers University of Technology has a strong emphasis on problem-based learning (PBL) which is fundamentally based on the CDIO syllabus. The courses included in this study are Machine Elements (“Maskinelement”, PPU210, 2016), Product Planning - Needs and Opportunities (PPU085, 2016) and Engineering Design & Optimization (PPU190, 2016). In order to effectively execute the CDIO-based project assignments within the timeframe of the course schedule, students need the knowledge and experience of design tools and methods beforehand or alongside the project execution. In the current scenario, the design tools and methods are given to the students through lectures by the professors and project supervision session by the teaching assistants (TAs).

The three CDIO-based project courses faces a number of challenges. The project execution in the considered courses usually requires close supervision and tutoring for the students. There has been a trend observed that the students demand more supervision time during the project execution which puts constraint on the amount of resources to be allocated. Further, the regular supervision time assigned in the course is often used to troubleshooting and to answer trivial questions from the students which does not contribute to develop a deeper understanding of advanced concepts. Other practical constraints experienced during the courses are delays in the start of project by the students, for example due to a lack of motivation or that some students miss assignment or lecture sessions if they are not mandatory. Video-based lectures or instructions might be a way to address those challenges and are tested in this study.

This paper aims at demonstrating the applicability of video-based learning in CDIO-based project courses and at evaluating to what extent it benefit students. The paper will also demonstrate the pilot process used in video development and provides recommendation for future usage of VBL. The questions raised here are:

- Is the video-based learning (VBL) format suitable for supporting CDIO-based project courses?
- What are the key features (video length, difficulty level, scope for video content, etc.) to take into account for video development from students’ perception?
• What are the perceived advantages and drawbacks with VBL for supporting CDIO-based project courses?

The paper is divided into the following sections; literature review, method, course description, results, and discussion followed by conclusion. The literature review investigates the prior work in the areas of blended learning, PBL and VBL. The method section highlights both the methodological approach that was applied for this study along with the methods used to generate the videos for the courses. The next section briefly introduces the studied courses and characterizes the project assignments according to the CDIO syllabus. The results section presents the outcomes of the quantitative and qualitative evaluation of the VBL in the different courses from the student’s perspective. The results are then discussed in the section including recommendations for using VBL in project courses. Finally, the conclusion presents the overall reflection of VBL for a CDIO-based project course.

LITERATURE REVIEW

In this section, a brief review of the work in the area of blended learning, video-based learning and problem-based learning is presented. The aim is to identify the trends, opportunities and constraints within each area and highlight the gap which can be fulfilled by combining the three areas stated above.

The term blended learning encircles any combination of learning delivery methods such as traditional lectures, and computer technologies (So & Brush, 2008). One method to create a blended learning environment is through the utilization of videos in project-based courses. Garrison & Kanuka, (2004) describe blended learning as an effective and low-risk strategy for universities to position themselves alongside the ongoing development in technology which fundamentally alter the way we learn. There are many considerations to be made in order to effectively utilize blended learning such as; planning, resource allocation, scheduling, and support for both students and teaching staff (Garrison & Kanuka, 2004).

The use of video lectures in higher education has gained popularity in recent years. This trend is supported by popularity of Massive Open Online Courses (MOOCs) and pedagogies such as the Flipped Classroom model (e.g. Yousef et al., 2014; Svensson et al., 2015). Alongside these, there have been many successful use cases of VBL reported from different universities across the world in the CDIO community. One common denominator from CDIO papers is the generally positive feedback that students gave to VBL. Benefits observed through the use of VBL are an increased flexibility in learning, the complementation of course material, an increased students control over their pace of learning and the creation of extra time that can be used for discussions and active learning activities (Viksilä, 2013; Sellens, 2014; Cronhjort & Weurlander, 2016; Demaziere et al., 2016). Unlike for student satisfaction with VBL, there is only limited empirical evidence regarding positive effects of VBL on the students’ performance and learning (Cheah et al., 2016;; Gommer et al., 2016; Hugo & Brennan, 2016; Schminder et al., 2016; Stöhr et al., 2016).

Problem-based learning (PBL) has been in use for the past 25 years. There are varied advantages highlighted in the literature such as higher motivation, increased understanding and experience-based learning with respect to the course topics (Prince & Felder, 2007). At the same time, the implementation of PBL requires a spectrum of instructional features such
as: provoking the students’ interest; experience in teaching to handle logistical and interpersonal problems; confidence in subject knowledge; and excessive time (Prince & Felder, 2007). Blumenfeld et al. (1991) describe PBL as a tool to engage students in the investigation of real world problems. They emphasize that the teacher’s responsibility for providing activities, instructions and managerial roles plays a crucial role for the successful implementation of PBL, which can, but does not necessarily have to, be supported by technology. Macías-Guarasa et al. (2006) showed the complexity and management requirements for project-based design for electronic systems curricula, which resulted in increased motivation and improved students’ performance. On similar grounds, the CDIO initiative has a strong focus on supporting design-implement projects (CDIO Standard 5) which is one form of PBL (Crawley et al., 2014). Edström & Kolmos (2014) showed the similarity and compatibility between CDIO and PBL, and further highlighted the need to take inspiration and learning from both approaches. A recent study examining VBL in a flipped classroom setup for project-based design course observed that on the one hand, students were offered extra opportunities to practice the engineering design process under supervision as the major course contents were covered in video lectures, but that on the other hand there was no significant increase in the students’ learning performance (Saterbak et al., 2016). Prince & Felder (2006) argue that inductive methods of teaching such as PBL can be successful depending on how much care is put forward in the course design and implementation. They conclude that PBL can result in inferior learning outcomes and unsatisfied students, if the appropriate amount of guidance is not provided.

Based on the literature review, it can be concluded that VBL can be successfully used to manage the excessive demands on teachers expected by students, and thereby increase the motivation of students in the CDIO-based project courses. However, there is still a need for in-class supervision sessions in order to provide guidance for problem-based learning. Thus, blended learning environments appear best suited to achieve this balance, but the design process requires an investigation as carried out in this study. The inclusion of videos into a CDIO-based project course will add an extra dimension into the course and students’ feedback will serve as an important input to develop this.

METHOD

An action research method was applied to perform a case study on the applicability of the video-based learning in the CDIO-based project courses. Avison et al. (1999) described action research as the combination of theory and practice; and is an iterative process for a particular cycle of activities. Action research is conducted by setting four premises: establishing purpose of research; setting practical actions; practical action relation with theory; and reasoning by the collaborative team involved (Baskerville & Myers, 2004).

The research was divided into three phases consisting of development-use-evaluation. Firstly a set of videos was created on selected topics for each specific course. Secondly, the videos were then used in the courses and the students’ feedback was collected by conducting a dedicated survey, the regular course evaluation questionnaire, and in student-teacher meetings during and after the courses. Lastly, the collected data was analysed to produce inferences about the applicability and utility of the video lectures/instructions. The results from the survey were used to identify indicative trends in the different courses.

The survey consisted of open and closed questions for capturing the students’ perspective on using videos in the three courses. The closed questions addressed the students’ behaviour and video usage, the preferred length and difficulty level, and their opinion about the future use of videos. The open questions gathered qualitative feedback about the perceived benefits and drawbacks of using video in the CDIO-based project courses. In order to receive the most constructive feedback, a dedicated survey was carried out at the end of the course so that the students had finished the projects and could provide a holistic perspective of the course and videos.

**Video Development Process**

The video development for each course followed a peer-review process as defined by Figure 1. The aim with this process was to create quality content. In total, 22 videos were developed for three courses under consideration. The relevant topics for the project execution were identified based on the content of the project, and past experience. The learning objectives for the videos were mapped based on the learning objectives from the project or the course (CDIO Standard 2) using constructive alignment (Biggs, 1996). This also served as an index for the viewer on what set of learning was expected from video. The content of the video followed the learning objectives and consisted of interactive experience covering the method(s) or tool(s) followed by example(s) or demonstration(s) (CDIO Standard 7).

The developed content was peer-reviewed by the internal development team for the course with immediate feedback. The purpose of the review before the recording was to attain the desired quality and minimize the amount of necessary changes after the video has been recorded. The video recording was carried out in different formats depending on the content and choice of the instructor. The typical format included: PowerPoint presentations, computer-screen recordings for tool demonstrations, mathematical problem solving, etc. The generated videos were again reviewed by the development team to give feedback. If major changes were required, the video was re-recorded. The videos were then used during the course in different format such as advance instructions, flipped classroom, etc., (CDIO Standard 8).

**COURSE DESCRIPTION**

Within the considered courses in this paper, the CDIO-based project assignments can be categorized as close-end, open-end, and semi-open-end project assignments. A close-end
project is characterized by a well-defined problem with a fixed input data set and students are expected to utilize the knowledge of design methodologies and tools to generate a specific solution for the problem. An open-end project assignment is characterized by the limited input data/information provided to the students and opportunity to produce variable solution output for the project. An open-end project typically originates from industry which is classified as; technology push and market pull projects. A semi-open-end project is on the middle of the continuum of the above two where the students are given a defined problem and are expected to utilize the design methodologies to produce alternative solutions for the project. For all the projects, the supervisors were expected to guide the students with the design methodologies, and the concepts associated with the problem. The short project assignments approximately ran for 2-3 weeks of time whereas the long project ran between 7-8 weeks of time. Both type of project assignment were resource-intensive. The short project assignments required more frequent meetings with supervisors compared to the long project assignments. Table 1 represents the three courses considered in this research and their respective project assignments characteristics. Table 1 represents the three courses considered in this research and their respective project assignments characteristics.

The purpose of video lectures differs somewhat in each course, though in general they are used to support CDIO-based project assignments. The PPU210 course is a large course (up to 180 students). Supervision demands are high accordingly and can only be handled through several tutors. However, the course has been criticized for providing disparate information. One objective of videos is therefore to provide uniform information about the project, systematic design methods and motivate students to move forward in projects. For the PPU085 course, the CDIO-based project assignment are performed in collaboration with different industrial partners. The idea with the videos in this course is to provide students with descriptions of design methods ahead of time. This should enable them to manage the project properly and give them a head-start with the project execution. In the PPU190 course, students

Table 1. Represents the characterization of CDIO-based project for each course.

<table>
<thead>
<tr>
<th>Course: PPU210 - Machine Element - Year 2</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>The student should attain deep, basic understanding about selection of machine elements which is of central importance in mechanical engineering. The machine elements covered in the course are: rolling bearings, hydrodynamic plain bearings, bolted joints, linear springs, brakes, toothed spur gears and belt transmissions.</td>
<td>No. of students ~ 180</td>
<td>No. of supervisors ~ 6</td>
<td>Group size: 2</td>
</tr>
<tr>
<td>Project Assignments</td>
<td>Type</td>
<td>Duration</td>
<td>Characteristic</td>
</tr>
<tr>
<td>PA1- Shaft and Roller Bearing Design</td>
<td>Semi-open-end</td>
<td>Short - 2 W</td>
<td>CDIO</td>
</tr>
<tr>
<td>PA2- Hydraulic Cylinder</td>
<td>Close-end</td>
<td>Short - 2 W</td>
<td>CDIO</td>
</tr>
<tr>
<td>PA3- Gearbox for metal lathe</td>
<td>Close-end</td>
<td>Short - 2 W</td>
<td>CDIO</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Course: PPU085 - Product Planning - Needs and Opportunities - Year 4, 5</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>The student should develop an understanding of how product development coincides with business development and the fundamentals of product planning and analysis of different stakeholders’ needs and requirements.</td>
<td>No. of students ~ 50</td>
<td>No. of supervisors ~ 10</td>
<td>Group size: 4-6</td>
</tr>
<tr>
<td>Project Assignments</td>
<td>Type</td>
<td>Duration</td>
<td>Characteristic</td>
</tr>
<tr>
<td>PA1- Market, Technology and Competitor Analysis</td>
<td>Open-end</td>
<td>Long - 7 W</td>
<td>CDIO</td>
</tr>
<tr>
<td>PA2- Customer Needs Mapping</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PA3- Product Development Project Plan</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Course: PPU190 - Engineering Design and Optimization - Year 4, 5**

The student should integrate traditional design methodologies with concepts and techniques of modern optimization theory and practice. With the approach and instilled knowledge the student is expected to be able to create design solutions that are creative and have better performance compared to traditional conservative methods.

<table>
<thead>
<tr>
<th>No. of students</th>
<th>No. of supervisors</th>
<th>Group size</th>
<th>Number of videos</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>~45</td>
<td>~2</td>
<td>2</td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

**Project Assignments**

<table>
<thead>
<tr>
<th>Type</th>
<th>Duration</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA1 - The Cantilever Challenge</td>
<td>Short - 2 W</td>
<td>CDIO</td>
</tr>
<tr>
<td>PA2 - Redesign, material selection and optimization of a failed product</td>
<td>Short - 2.5 W</td>
<td>CDIO</td>
</tr>
<tr>
<td>PA3 - Multi-objective optimization of an engine encapsulation component (MDO)</td>
<td>Short - 2.5 W</td>
<td>CDIO</td>
</tr>
</tbody>
</table>

Table 2. Represents the classification of videos according to CDIO syllabus.

<table>
<thead>
<tr>
<th>Conceive</th>
<th>Design</th>
<th>Implement</th>
<th>Operate</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEST analysis</td>
<td>Function Structure</td>
<td>Design of Experiments</td>
<td></td>
</tr>
<tr>
<td>SWOT analysis</td>
<td>Morphological Matrix</td>
<td>Prototyping lab machine tutorials (multiple)</td>
<td></td>
</tr>
<tr>
<td>Benchmarking</td>
<td>Kesseling Matrix</td>
<td>Software Tutorial</td>
<td></td>
</tr>
<tr>
<td>Questionnaire design</td>
<td>MATLAB Optimization</td>
<td>(MATLAB, COMSOL, CATIA, JMP Suite, etc.)</td>
<td></td>
</tr>
<tr>
<td>Customer need elicitation</td>
<td>FMEA</td>
<td>Material Selection</td>
<td></td>
</tr>
<tr>
<td>Market identification and selection</td>
<td>SFD and BMD construction</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bearing Dimensioning</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Screw Design</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gear ratio for lathe</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The results section is divided into two parts, the quantitative survey data indicating the students' preferences and usages of the videos and the open answers regarding the perceived advantages and drawbacks of videos. In total, 143 responses was received out of which 85 (59.4%) were from PPU210 course, 17 (11.9%) from PPU85 and 41 (28.7%) from PPU190 course. Figure 2 shows six bar plots with the student answer distributions to different questions about their watching preferences and behaviour in the three courses.

With regard to student interaction with the course videos, Figure 2 (a) shows that for PPU210 and PPU190 course, around 60 to 70% of students watched the videos, and at least in parts even more than one time. On the other hand, in the PPU085 course only one third of the students used the videos in this way. 20% even did not watch the video at all (the “other”...
category) because they were not aware or reminded of the videos. This observed difference in interaction patterns between the courses might be related to the different contents of the videos. The videos presented in PPU210 and PPU190 were tutorial/instructional videos that could be used for working on the project assignments, whereas PPU085 contained lecture-based content.

Figure 2 (b) shows the students’ preferred video length from the three courses. The majority of students in all the three courses indicated that a video of up to 10 minutes is suitable. But the data also indicate that for almost 40% of the respondents in PPU210, the video length did not matter and this number correspondingly decreased for the PPU190 (25%) course and PPU085 (12.5%). The probable reason for is that the PPU210 course has close-ended projects for which the video content became more relevant to the project execution.

Figure 2 (c) presents perceived level of difficulty level of the videos. The vast majority of students found the content to be at the right level or somewhat too easy. The videos were usually aimed to be short (5-15 minutes) which sets limits to the level of detail in the topic descriptions. It can be noted that more than 50% in PPU085 course found the content be at low level which is consistent with the scope of the course which is not technical.

Figure 2 (d) shows the level of agreement with the statement “the videos helped me to prepare for the project assignment” which was the initial motive for the using video in the CDIO-based project courses. The videos were highly appreciated by the students in all three courses as in average about 80% of the students agreed or strongly agreed that the videos were helpful.

Figure 2 (e) depicts the students’ general attitude towards using VBL before the start of the courses. Although between a third and half of the student in the courses stated that videos made the course more appealing, most students were indifferent.

Figure 2 (f) shows students’ attitude towards using videos after the course and there are few notable observations in comparison with Figure 2 (e). For PPU190 and the PPU210 course, the students’ opinion shifted positively towards VBL. In both courses, about 50% of the students preferred videos and one tenth even strongly preferred VBL. The probable reason is the close alignment of the video content with the project assignments. On the other hand, after the PPU085 course, only 28% preferred videos. About the same amount preferred traditional classroom teaching and almost half of the students had no preference. This result is consistent with the interaction patterns from Figure 2(a), indicating that the students were not able to utilize the videos to the same extent as in the other two courses and that the open-end projects in PPU085 require more face-to-face interaction and discussions with teacher.
Student perceptions of benefits and drawbacks of using videos in PBL

In two further open questions, we asked students where they see the main benefits and drawbacks of using video lectures. We collected the answers for all three courses and

categorized them in main categories. The ten most frequently named categories can be found in Table 3.

Table 3. Student’s top ten benefits and drawbacks of using videos in PBL

<table>
<thead>
<tr>
<th>Benefits of videos (N*=129)</th>
<th>% of N</th>
<th>Drawbacks (N*=89)</th>
<th>% of N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Can be watched repeatedly</td>
<td>63</td>
<td>Cannot ask questions immediately</td>
<td>38</td>
</tr>
<tr>
<td>2 Easy access anytime and anywhere</td>
<td>22</td>
<td>Lack of deeper information and topics</td>
<td>8</td>
</tr>
<tr>
<td>3 Can be watched at own pace (pause, rewind, jump)</td>
<td>14</td>
<td>Poor video quality</td>
<td>6</td>
</tr>
<tr>
<td>4 Better compared to other formats (e.g. ppt, pdf, mp3)</td>
<td>8</td>
<td>Project assignments become too easy</td>
<td>4</td>
</tr>
<tr>
<td>5 Can be used while working on the project assignment</td>
<td>8</td>
<td>Less motivating, easy to skip</td>
<td>4</td>
</tr>
<tr>
<td>6 Allows to catch up if one misses a lecture</td>
<td>6</td>
<td>Videos are misleading</td>
<td>4</td>
</tr>
<tr>
<td>7 Possibility to select and skip known parts</td>
<td>5</td>
<td>Hard to find relevant content</td>
<td>3</td>
</tr>
<tr>
<td>8 Additional explanations</td>
<td>5</td>
<td>No face-to-face contact to the teacher</td>
<td>2</td>
</tr>
<tr>
<td>9 The assignments become simpler</td>
<td>3</td>
<td>Bad pedagogic quality</td>
<td>2</td>
</tr>
<tr>
<td>10 No need to ask teacher for clarification</td>
<td>3</td>
<td>No drawbacks</td>
<td>28</td>
</tr>
</tbody>
</table>

*N = number of students that answered the question.

The by far most frequently mentioned benefit of videos was the possibility to watch them several times be it as preparation for the exam or if a concept was not understood during the in-class lecture. Further, students frequently saw the increased flexibility in terms of where and when and at what pace to watch the lecture as a benefit. For example, several students wrote that they feel more comfortable at home, or are more productive in the evening hours. Some students also argued that it is easier to learn from videos compared to slides, text documents, or audio recordings, partly due to the opportunity to better visualize critical aspects. A number of students particularly from the Engineering Design and Optimization (PPU190) course and the Machine Element (PPU210) course underlined the usefulness of videos for conducting the assignments. The videos did not only have further explanations that could accessed in relation to the specific knowledge gaps of the student, they also can be used in parallel while working on the assignment. In sum, those benefits reflect the increased flexibility and possibility to adapt the learning process to the individual needs of the student.

The most significant drawback of using video lectures was seen in the missing opportunity to ask immediate questions. Even if the possibility to ask questions via email or the next in-class session was given, over one-third saw this as a main drawback. Student’s further expressed concerns regarding the lack of deeper information and the limited amount of relevant content that, in addition, can be difficult to find and misleading. Others thought that the assignments became easy compared to attempts to solve those without the additional explanations, which can be perceived as unfair. Finally, a few students criticised the poor video quality (e.g. resolution, audio), the lack of face-to-face contact with the teacher, the lack of motivation to watch videos or the general poor pedagogic quality of videos as learning material. However, interestingly, more than one-fourth did not see any drawbacks at all. In sum, those drawbacks point at the lack of social interactivity of video lectures as well as the challenging pedagogic and technical design.

DISCUSSION

The overall positive student feedback about the use of videos in the three courses supports the conclusion that VBL is suitable for CDIO-based project assignments. Nevertheless, there is a need to further develop the pedagogics of using videos for such courses in order to make VBL more attractive and useful for students. The perceived benefits and drawbacks of VBL that the students expressed are similar to the findings from other studies (e.g., Viksilä, 2013; Sellens, 2014; Cronhjort & Weurlander, 2016; Saterbak et al., 2016), although this study particularly highlights the benefits of VBL for PBL and the importance of aligning the videos to the other learning activities.

The next research question was to examine key features for the video development from the students’ view. From the survey results students preferred a shorter video length of 10 min, which is consistent with other research (e.g., Oishi, 2007; Maniar et al., 2008, Guo et al. 2014). Nevertheless, it can be argued that the optimal video length depends on a multitude of factors such as the meta-cognitive abilities of the learners, the course’s scope and the video type. Students from the 2nd year are likely to possess only limited pre-knowledge and control over their learning which increases the possibility that they need more information and direct student-teacher interaction to successfully execute the projects. On the other hand, students from 4th and 5th year have broader knowledge from a wider set disciplines and are better equipped to develop individual learning and problem solving strategies and therefore can utilize shorter bits of video information more effectively to get an understanding of the topics.

The scope of the course can also influence the preference for video length. For example, PPU210 contains detailed design theories for which well-elaborated explanation are required, whereas PPU085 and PPU190 contain topics that are more on an applied level and cover wide areas of application. Finally, the group sizes for the project assignments also varied between the courses and may influence the interaction with the course videos. However, the data gained in this study do not allow for any causal conclusions and has to remain somewhat speculative, but one can once again stress the importance of a constructively aligned approach to video development which appears somewhat easier to achieve for tutorials that connect well with the actual project assignments.

In terms of the level of difficulty, the study showed that the students majorly found the videos to be at the right or lower levels for all the courses. This finding connects to the discussion of video length since, short videos do not leave room detailed topic descriptions and the information was presented in summarized form. In addition, in PPU085 and PPU190 the incoming students had different master programs, partly from other universities, as background and one purpose of the videos was to bridge the gaps in the pre-existing knowledge of the students that was relevant for the assignments. Thus, even though it appears that the videos served this purpose well, they had to be kept on an introductory level. In order to include contents on a higher difficulty level, more video time would be required, which could be handled by splitting the video content into smaller chunks. However, this will pose a challenge in managing and presenting such information which will require further development in pedagogics. Eventually, learning analytics could help in this process by

identifying topics and video parts of higher and lower relevance to the students (e.g. Demaziere et al. 2016)

The type of the video, appeared to have a strong effect on student perceptions and usage of the videos. As outlined earlier, the videos presented in PPU210 and PPU190 were tutorial/instructional videos whereas PPU085 contained lecture-based content. The tutorial/instructional videos were actively used by the students and very positively evaluated. The tutorials enabled the students from different backgrounds to reach the learning level necessary to do the assignments, which required an intensive use of software, such as MATLAB. On the other hand, the PPU085 course is more qualitative in terms of methodologies and students showed less interaction with the videos and an inclination towards traditional classroom teaching, where it is possible to have face-to-face discussions. Videos were seen as a backup option.

From a teacher's point of view, the success factors for the VBL can be seen in a long term perspective. Videos for the course can be generated in stages, with incremental improvements and formative feedback over years. Students can watch videos in a flexible way, selective and at their own pace depending on their need and prior (gaps in) knowledge. In a long-term perspective, using videos can be seen as an effective way of improving the course. Advantages observed here included an increased uniformity in instructions, less dependency on supervisors and online support resulting in more flexibility for student learning. In order to maintain the quality of the videos, guidelines for generating videos need to be developed in the future.

As the final part of this discussion, there are also a few concerns and limitations. First of all, since this study was limited to student perceptions, there was no investigation whether VBL had an actual effect on the students' performance and learning. Thus, while the results of this study are in line with research on student satisfaction in blended learning, no conclusion can be made to the discussion around VBL effects on student learning. Using videos also poses drawbacks in that there is a risk that instruction becomes too transparent and only one-way as evidenced by the student answers in this analysis. Just as in-class lecturing should be combined with active learning exercises to induce deeper learning, VBL needs to be combined with other forms of student engagement. In PBL, this appears the case which requires careful planning of video content so that it is aligned with the course project assignments, as the content cannot be spontaneously adapted as in regular classroom teaching. Further, VBL might fail if it is not introduced properly and students fail to see the benefit and how the videos contribute to achieve the intended learning outcomes. During the feedback in course evaluation meeting, it was suggested by the students to use more structured way of presenting videos in course introduction and to highlight the differences between what will be presented in traditional classroom teaching and what will be presented in video lectures/instructions. Lastly, a from the students' perspective serious limitation of using videos is the lack of immediate feedback to questions that students have while and after watching the videos. This is an interesting aspect for future research. On the one hand, further studies can attempt to address this issue by for example testing clearer instructions to the students about how they can communicate with the instructor, one could also develop and test tools and techniques that provide feedback without the exclusive reliance on the teacher. That might for example involve forums, FAQs, Wiki’s and social media platforms or even computer-generated automated feedback. However, another way of looking at this
issue of “not able to ask immediate questions” is that it encourages students to think more intensively for themselves and encourages them to look for additional learning resources or discuss the question with their peers. Future iterations of the courses will try to address these concerns.

CONCLUSION

This paper examined the applicability of videos in three CDIO-based project courses. Based on student feedback via a survey, the course evaluation and group meetings, the analysis showed a positive response of students to the videos. They found them particularly suitable to work with design-build-test assignments. As a main benefit, the videos provided flexibility to the students as they get an extra online support that they can access at any time and study at their own pace during the project assignments. This helped reinforcing concepts, and enabled less dependency on supervisors during project execution. In order to maximize student satisfaction and interaction with the videos, the videos should be short and closely aligned to the other learning activities. Videos proved to be suitable for creating a blended learning environment and improved the perceived learning experience for the students. Further pedagogical development is nevertheless needed to improve the utility and attractiveness of videos into the course.

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TO TEACH IS TO LEARN: STUDENT AND INSTRUCTOR PERSPECTIVES ON ASSIGNMENT DEVELOPMENT AS A SPRINGBOARD TO DEEP LEARNING

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ABSTRACT

Of the three levels of learning – surface, strategic, and deep (Bain, 2004) – the traditional lecture style combined with large class sizes often found in engineering and science programs tends to encourage surface learning. Students may not progress to, or past strategic learning because the motivation to understand concepts beyond attaining a desired grade can be limited. The Canadian Engineering Accreditation Board (CEAB) Graduate Attribute performance criteria target deep learning with the demonstration of synthesis and evaluation of concepts. Engineering graduates should be able to create and evaluate innovative solutions for a sustainable world. During an eight-month co-op work term, two of the authors were employed to develop instructional materials for an introductory chemical engineering design course. Our goals were to develop design lab assignments to support deep learning; target Bloom’s higher level cognitive and affective domain skills; support contextual knowledge experience, and achieve progress in all CEAB graduate attributes. Through this experience, the co-op students gained a deeper level of understanding of the materials than achieved after completion of the course for credit. This paper explores their experience; the instructors’ experience; the structure of their work; and the method of assignment design, development, and testing. Engineering instructors can encourage and abet deep learning of course materials by incorporating opportunities for peer teaching, peer editing interactions, and relevant assignment development experiences. Illustrative design course examples, and our reflections on outcomes are presented and discussed.

KEYWORDS

Peer Teaching, Deep Learning, Design, Integrated Learning, Active Learning, Collaborative Learning, Faculty Development, Action Research, CDIO Standards: 1, 2, 3, 5, 7, 8, 9, 10, 11

INTRODUCTION

The expectation that learners are required to teach has the potential to transform how we learn (Nestojko, 2014). Peer teaching and evaluation were employed as a structured method
to format the work of co-op students hired to develop learning materials for a chemical engineering process design course. Two students were hired for a four-month work term and two were hired for an eight-month work term. All four co-op students contributed to assignment and quiz design for four months and had previously completed the introductory undergraduate design course. The two students completing eight-month work terms provided peer teaching in the design lab as undergraduate lab assistants and reflected on their own learning as they continued to develop assignments. These students also researched learning methods, reflected on their experience, and presented their findings at a conference. The process followed was to conceive, design, implement, and operate in the context of Process Design lab assignments. This paper reports on the peer student teaching/mentoring experiences (students transformed into teachers) and the instructors experience in guiding them. The benefits of employing peer teaching and mentoring for course instructors, student mentors, and undergraduate students taking the design course are presented and discussed.

LITERATURE REVIEW

Deep learning (Bain, 2004) opportunities and the expectation of using learned material in an anticipated teaching activity (Nestojko, 2014) support skill development. The expectation of performance is also linked to learning and motivation (Biggs, 1999, 2003; Biggs and Tang, 2011). Learning is meaning centered and constructed in context and often motivated by the context (Resnick and Klopfer, 1989). Collaborative Learning techniques have been used in multiple contexts (Heller, 1992) to promote student achievement. Hattie (Hattie, 2009) reports the highest ranked factors for teaching or teacher related effects are: formative feedback to teachers (d=.90), teacher clarity (.75), reciprocal teaching (.74), feedback (.73), spaced vs. mass practice (.71), metacognitive strategies (.69), self-verbalization/self questioning (.64), professional development (.62) and cooperative vs. individualistic learning (.59). Reciprocal teaching is an activity where teachers and students share the role of teaching. By comparison the highest ranked factors for students are: self-reported grades (1.44); concentration, persistence, and engagement (.48); and gender (.12). This suggests that choices made by instructors have a greater impact on student achievement than student empowerment. Group work and collaboration further encourage metacognition as students solve problems (Metcalf, 2008) and reflect on their learning (Bain, 2012). Student choices and decisions impact their learning outcomes, while instructor choices impact students’ participation in the higher impact activities. Some students develop a deep transformative learning orientation by turning failure into opportunities and using reflection to navigate murky situations (Bain, 2012). This learning orientation, coupled with instructor created opportunities for student teams to engage in self-directed outcome-oriented learning leads to meaningful mentorship opportunities, fosters deep learning, and provides an empowering environment for student achievement and life-long learning skill development. By engaging with the co-op students in course preparation and delivery, the instructors expected to lever the learning effects bolded above, in particular, to move the co-op students working with us and students taking the course for the first time from surface or strategic learning toward deep learning as a life long practice. Action research, (Carr and Kemmis, 1986; Kember, 2000; Kemmis and McTaggart, 1988; Case and Light, 2011) a methodology where research is done with subjects and not on them, is described as “taking place within everyday, natural contexts rather than controlled settings” (Cousin, 2009). The aims and benefits of action research are the strategic improvement of practice (Case and Light, 2011).
Often utilizing a continuous cycle of four movements: a plan of action for improvement, action to implement the plan, observation of the effects in context, and reflection on these effects as the basis for future improvements and planning (Kemmis and McTaggart, 1988), action research is similar to the conceive, design, implement, operate process. The metacognitive strategy of reflection on in-context observations coupled with implementation and operation experience influences the achievement of deep learning.

**METHOD**

We used a case study methodology to follow the assignment development progress. The co-op students and instructors reflected on their personal observations and learning as the conceive-design-implement-and-operate process unfolded. The situative learning framework defines knowledge “as distributed among people and their environments, including objects, artifacts, tools, books, and the communities of which they are a part” (Greeno, Collins & Resnick, 1996). Learning is seen as meaningful participation in a community of practice (CoP) (Johri and Olds, 2011). The case study approach in a CoP context was intended to draw out the learning of the team, and to examine the deeper issues in the experience described by Johri and Olds in a structured manner that includes action research and grounded theory. “Action research is simply a form of self-reflective enquiry undertaken by participants in social situations in order to improve the rationality and justice of their own practice, their understanding of these practices, and the situations in which the practices are carried out” (Carr & Kemmis, 1986). Action research methodology was used to classify experiences qualitatively and to make comparisons with accepted learning frameworks (Greeno, Collins & Resnick, 1996). We respected the dialectical nature (Case and Light, 2011) of the active research methodology.

The research questions we address are: Did the experience of preparing, implementing, adapting, and reflecting on course materials impact the nature of the learning (surface, strategic, deep) of the two peer instructor co-op students? Did the peer instructors abet the learning of the students taking the course for the first time? A peer work structure was conceived, designed, implemented, and then operated. The end objective of creating learning activities aligned with learning objectives, mapped to the CEAB graduate attributes, was specified and the process allowed to proceed organically. Work reports, reflections and discussions were reviewed for common threads and viewpoints, as well as differing perspectives. Summative qualitative reflections are included among the results. The case study was completed from an experiential viewpoint as the research questions were asked and answers obtained from our work team. Feedback from students to the peer instructors directly, and instructor observations also informed our reflections.

*Peer Work Structure – Developing Quizzes and Assignments*

The four co-op students on the work team previously completed design lab assignments for credit and indicated a high degree of motivation to work with minimal supervision in a team setting. The initial assignment development tasks were performed by pairs of students and based on previously completed assignments. Additional quiz questions were developed individually and tested by the paired students who gave feedback leading to a first revision. The revised questions were tested by one of the students working in the other pair and the
feedback revision process was repeated. Last, a fourth student tested the second revision and gave further feedback. Both pairs of students were given assignment development tasks with the expectation that the other pair would test the questions. This structure was maintained when the work progressed to developing new assignments. One pair of students designed assignment questions for an ethane + propane cracker and the other pair for a sulphur plant. None of students had prior experience with either chemical process. The assignments were further revised ahead of implementation (Fa16, and Wi17) by the instructors and the co-op students engaged in peer mentoring (Fa16).

**Training Provided**

The four co-op students attended teaching workshops provided by the University of Alberta Center for Teaching and Learning (CTL) including one by Ken Bain. The pre-reading required for this workshop was “What the Best College Teachers Do” (Bain, 2004). The students had the opportunity to learn effective methods (Hattie, 2009) for enhancing student achievement. The focus was on what an instructor could do. These methods were discussed along with their experiences and ideas at bi-weekly meetings and more frequently as the work transitioned from development to classroom implementation. The work term students were invited to consider the engineering education research aspects of the process and to investigate and apply education research to their work. They were invited to consider the possibility of developing research contributions based on their assignment development and peer teaching experiences in collaboration with the instructors!

**Design Course Context**

Chemical Engineering Design I is a 13-week course taken in the seventh semester of the chemical engineering undergraduate program. The course covers “engineering design concepts; cost estimation; project planning and scheduling; plant safety and hazards analysis; selected project design examples” (University of Alberta Course Catalogue, 2013). Eight weeks are spent in a lecture format with weekly lab assignments. Five weeks are dedicated to work on introductory-level design projects. The class is divided into groups of three or four students at the beginning of the course, and these groups work together on lab assignments and design projects. Lab assignments concern engineering design topics and are due weekly. The first assignment, an introduction to the course and to design analysis, and the last assignment, on the use of an advanced steady-state process simulator (VMGsim) are fixed. Six other assignments vary in detail from term to term and address: flowsheets; fluid movers; heat exchangers; reactors; separation vessels; and costing and economics. From a teaching methodology perspective, the course can be described as employing a cognitive framework (Greeno, Collins, and Resnick, 1996) for the lab assignments and it then introduces a situative framework for the design project. The situative framework is also employed in the follow up Capstone Process Design course. The attributes of these comparative frameworks were tabulated by Johri and Olds, and are rehearsed here as Table 1.
RESULTS AND DISCUSSION

Overview

The co-op students first explored the generation gap between instructors and students in courses and researched how to bridge the gap. They presented their reflections on the development of the internet and the impact it has had on the way instructors and students interact with information, learn, and how to bring the classroom forward into the 21\textsuperscript{st} century at the 2016 CSChE Conference Chemical Engineering Education Symposium as “Improving the Learning Experience for Millennials, by Millennials”. The peer teaching students also presented a preliminary version of the present contribution as “To Teach is to Learn” at the same conference and won second place in the Reg Friesen competition (Figure1). More importantly, the peer mentor students and instructors classified their collective experience as a deep learning experience – the students were motivated to learn more than they had learned while taking the introductory design course for credit, and continued learning about design and teaching. Mentoring and teaching their peers in the classroom was rewarding for them and for the students they mentored. Their peer-mentor role complimented the more

<table>
<thead>
<tr>
<th>Framework</th>
<th>Behaviorist</th>
<th>Cognitive</th>
<th>Situative</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Nature of Knowing</td>
<td>Knowing as having associations</td>
<td>Knowing as concepts and cognitive abilities</td>
<td>Knowing as distributed in the world</td>
</tr>
<tr>
<td>The Nature of Learning Transfer</td>
<td>Acquiring and applying associations</td>
<td>Applying and using conceptual and cognitive structures</td>
<td>Becoming attuned to affordances and constraints through participation</td>
</tr>
<tr>
<td>The Nature of Motivation and Engagement</td>
<td>Extrinsic motivation</td>
<td>Intrinsic motivation</td>
<td>Engaged participation</td>
</tr>
<tr>
<td>Guidelines for Design of Learning Environments</td>
<td>*Routines of activity for effective transmission of knowledge *Clear goals feedback and reinforcement *Individualization with technologies</td>
<td>*Interactive environments for construction of understanding</td>
<td>*Environments of participation in social practices of inquiry and learning *Support of development of positive epistemic identities</td>
</tr>
</tbody>
</table>

Table 1. Learning Frameworks Comparison (Johri and Olds, 2011)

| Guidelines for Curricular Design | *Sequences of component to composite skills* | *Sequences of conceptual development*  
|                                  |                                           | *Explicit attention to generality*  
|                                  |                                           | *Development of disciplinary practices of discourse and representation*  
|                                  |                                           | *Practices of formulating and solving realistic problems*  
| Guidelines for Assessment Design | *Assessment of knowledge components*  
|                                  | *Assessment of extended performance*  
|                                  | *Crediting varieties of excellence*  
|                                  | *Assessing participation in inquiry and social practices of learning*  
|                                  | *Student participation in assessment*  
|                                  | *Design of assessment systems*  

formal instructor-student interaction and facilitated learning. All four co-op students were motivated to develop assignments that were targeted to achieve the course learning objectives while minimizing workload. They had the experience of completing their seventh of eight academic terms and had first-hand design experience to draw on. They understood the course objectives, the context of the CEAB graduate attributes, and had gained experience teaching each other prior to their opportunity to become peer mentors. The preparation of the assignments with the expectation they would teach further motivated the peer mentor students to ensure that they understood how to explain the questions and concepts to students taking the course for credit. The students taking the course for credit asked instructors and peer mentors for guidance. The peer mentors asked one another and the instructors guidance. The peer mentors provided a viewpoint that the work was possible and that undergraduate students could achieve higher cognitive task levels in the design lab assignments that they helped design and test. Peer mentors were not used in the previous or following offerings of the course and instructors were much busier during design labs with questions even though teaching assistants were available. Students taking the course for credit actively sought the advice and assistance of the peer mentors, underscoring the credibility of their contributions. The majority of the students in the class was also keen to support the peer mentors and completed voluntary consent forms so that photos including them and the peer mentors could be used for publication.
Co-op Student Peer Instructor Reflections

Peer instructor #1: At the start of the work term, I was skeptical about what I would be able to obtain from this job. I saw field engineering work as superior because I would see how people and equipment work at a fundamental physical level. I saw office engineering work as superior because I could see how corporate workers collaborate to design and carry out technical projects. I felt working for the University of Alberta as a course development assistant wasn’t the best choice for my last work term, as I would only be obtaining more theoretical knowledge. I was both right and wrong. I was right that I would be mostly obtaining more theoretical knowledge. I was wrong thinking that this was an inferior job opportunity because I acquired a lot more theoretical knowledge than I was expecting and the knowledge I acquired was at a much deeper level than what I obtained from my courses. Overall I feel more confident to tackle industrial problems now.

So why did I acquire a deeper level of understanding through my work term than through my courses? Because I was motivated to develop a deep understanding for the material rather than just understand it enough to get a good grade. I had been a strategic learner, I learned as much as I needed to in order to do well on the exams - nothing more, nothing less. I had nothing motivating me other than getting a good grade and I was already getting a good grade. When in school, there is so much material being bombarded at me that even for material that I’m interested in, I don’t have time to think about it and digest it. There is a constant need to move on to the next assignment or to the next course to study. Coupled with the likelihood that the vast majority of what we learn in school we will never see again and knowing a lot of the required learning will happen at the workplace, there just isn’t much motivation to understand the material besides getting good grades and hoping that means companies are more likely to hire me. Then there is the boring format that most lectures go through where the instructors just go up there and talk and there’s virtually no connection between students and instructors other than the occasional question. Boring lecture format
and a lot of boring material is a mixture that gives zero reason to learn any material. It was easy to get away with having gaps in my understanding and a superficial level of understanding during the design course as a student because the bulk of the course work was done in teams. I was fortunate enough to be in a group with highly competent team members and if I didn’t understand something, at least one of them did. So instead of learning about what I didn’t understand, I delegated the work in those areas to my team in order to save everyone time. When I was done the course, I got a lot better in areas that I was already competent in but my areas of weakness stayed where they were. This in part was reflected on the final exam for the course, I had no problems with questions on sections that I was familiar with such as equipment sizing and costing. But on the questions testing material that my group members took care of such as the theoretical design concepts behind equipment selection and how each piece of equipment worked, I struggled.

So how did my work this co-op term help me progress beyond strategic learning and into deep learning? The modules and assignments for the introductory design course are each based on certain pieces of equipment and certain design concepts. Without a solid fundamental understanding of these concepts and how equipment works, it is impossible to develop questions and to teach students the material. So if I didn’t actually understand the material, I essentially couldn’t do what I was getting paid to do.

Figure 2. Motivation: Responsibility for other students’ learning

Being able to do my work and appearing competent is one motivator, but the major motivating factor for fully understanding the material was the responsibility for other students’ learning. (Figure 2.) While in school, if I didn’t understand something, the only one that I was hurting was myself. As part of the instructional team, if I don’t understand something or if I have the wrong understanding of a concept, not only do I look foolish when the students ask me questions and I don’t know the answers or give them the wrong answer, but also the students may also not learn the material or learn it wrong. I interacted with these students for 6 hours a week in person and through email so the impact I had on these students was significant. The course started with over 100 students, so the impact of my inadequate understanding would be 100 fold. These 100+ students then have their own social circles which I would have an indirect impact on. Imagine if one of these students ended up working for a big plant some years down the road and because I taught them something wrong, they ended up blowing up a plant. That responsibility is on me. That situation may be a bit of a
stretch but I was absolutely not willing to let my own incompetence become the problem of 100+ students.

This concept of learning through teaching is nothing new. There have been numerous studies on the subject and some of the studies suggest that this is the very reason why the eldest sibling is the most intelligent in most cases (Kristensen, 2007). Some of the sources that support this idea and that we used for our presentation at the CSChE are included in the references.

Peer instructor 2: I collaborated in the development of an assignment set based on an ethane-propane cracker. It would be impossible to write assignments and accompanying solutions for material I was not certain about, and as such, it was necessary to be blatantly honest with myself as to which concepts I had not thoroughly learned previously. This was an interesting change of perspective, as I now took my learning of the material more seriously than when I had been going through the course myself. This time, not only was someone relying on me to perform accurate work, without the safety blanket of being an ‘introductory design student’, but others were relying on me to teach them these concepts accurately and quickly. The most obvious outcome of this was that my knowledge upon completion of my co-op term now greatly surpasses that of when I completed the introductory design course, and I am now much better at communicating ideas to classmates. While going through my academic career, and especially while I was an undergraduate lab assistant, I found there was an optimum point of communication – too little and the student does not have the full picture, but too much and the learning objective becomes confused. I focused on conveying the information to the student as completely, but as effectively and quickly, as possible.

To ensure maximum student learning without repetition or extraneous work, it is necessary to identify whether the information the students interact with in lecture is either primary design knowledge (knowledge gained in prior university courses or high school) or secondary design knowledge (new information learned in CHE 464, co-requisites, or professional experience). This categorization directly affects how the information is presented and how it is tested in the assignment set. By categorizing the level of understanding, it is possible to understand how to develop students’ critical thinking skills to the ‘creation’ level, based on the revised Bloom’s Taxonomy shown in Figure 3. Secondary knowledge must be taught gradually with more guidance to ensure that the students develop a proper conceptual framework. When primary knowledge is expanded upon, the students’ conceptual framework must first be addressed to ensure no misinformation, and then concept difficulty can increase quickly. One of the defining features of CHE 464 is the clear contextualization and real-life application of the processes and equipment examined. In every assignment and most of the lecture notes, students are asked to consider the equipment beyond simply sizing or costing. These considerations include: type of equipment used; safety and environmental risks and management methods; metallurgy and types of material concerns; equipment arrangement and location; accommodation for catalyst deactivation; and rationalization of compressor surge and process flare lines. None of these topics are discussed in course prerequisites but are at least as important as the sizing and costing of the equipment.

Instructor Reflections

Instructor 1: Initially my goals were to support the Faculty of Engineering co-op student employment program and diversify the question bank for the design lab assignments. It seemed like a good match. I was willing to invest some time. I knew other professors had successfully employed students to help develop assignments and I had been developing assignments myself for the design courses and collaborating with my teaching partners. I understood the value of having someone who had just learned or was still learning the material to help tune an assignment set to the abilities of the target student cohort. I planned to set up their work environment with peer accountability, flexibility, and self-management as characteristics of their work team. My management style is to hire talented people, give them training, a process, resources, my support, confidence, and expect them to deliver the product. I was reading Ken Bain’s book and knew he was presenting at the Summer CTL session.

I decided to invite the co-op students to the session and have them take notes for me at the sessions I wasn’t attending. I soon realized that they were very interested in making a difference and I gave them some opportunities to research teaching and learning and suggested that they might be able to present their work at a conference in the fall. They became very interested in developing their work from an academic perspective. Their desire to make a difference was clear. I also suggested that they would be helping in the design lab with the assignments they were developing (Figure 4). I could see their engagement developing as we interacted. Their ideas, knowledge, analysis, evaluation, and creative skills developed. At first they just copied the questions and changed the context. Then they began to develop skills to write better questions, to classify the questions with Bloom’s Taxonomy and critique the questions with respect to the learning objectives. They began to learn about generational traits, Internet development and the relationship to the traits, Bloom’s Taxonomy, learning objectives, and Bain’s levels of learning. By the end of the work term they were able to identify knowledge gaps and where leaps were being made that undergraduate design students found difficult to make with us. The two students who worked on the project for four months volunteered to come help in the lab to have the operate part of the design experience. For me this was an innovative and collaborative experience that enhanced my perspective of teaching and learning. It demonstrated to me how students could be empowered to develop

Figure 3. Bloom’s Taxonomy (Modified version 2012) (Armstrong, 2016)
a deep transformative learning environment. It emphasized the importance of the situation and intrinsic motivation in creating a meaningful contextual learning environment where students can construct their learning activities. As a result I am encouraged to include more peer teaching and mentoring activities explicitly in the course. Since design students are typically young adults with developing experience, the shift from a behaviorist to cognitive framework encourages the shift from extrinsic to intrinsic motivation for learning. In this case, the motivational shift to “engaged participation” appears to have been accomplished by the expectancy of meaningful contribution in a situative context (Greeno, Collins, and Resnick, 1996) and appears to have been causal in students shifting to a deep learning paradigm.

Instructor 2: When we embarked on this project, I knew we would obtain useful and flexible assignment and quiz question banks for the design course. I had not expected to learn so much, first hand, about how excellent and motivated undergraduate students view courses and their own course performance. I had also not appreciated the significance of the impacts of strategic task management within student teams on the perpetuation of technical knowledge deficits and hence on CEAB graduate attribute attainment. This heightens my desire to create environments and to motivate more students to move from strategic to deep learning as we further develop the curricula for both the introductory and capstone design courses.

CONCLUSIONS

Through collaborative development and implementation of engineering design lab assignments intended to be meaningful and constructively aligned learning experiences for undergraduate students taking the design course for credit, both instructors and peer mentors were able to reflect on how to assist chemical engineering graduates to become deep and lifelong learners. The process used to design the assignments essentially followed the conceive-design-implement-operate model and the peer teaching students were able to follow the process to the operate stage, reflect on the results, and make recommendations for improvement. Peer teaching and mentorship were used to promote both deep and lifelong learning. The operate stage clearly had an impact on the learning and motivation of the
By taking responsibility for the understanding of others, they were motivated to deepen their own knowledge. Students can create deep learning experiences when supported with a learning environment and a process that require them to design and perform meaningful contextual work including disciplinary practices of discourse and social practices of inquiry like teaching and mentoring peers.

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DESIGN OF LEARNING ARTEFACTS - PROTOTYPING CHANGE OF EDUCATIONAL CULTURE

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ABSTRACT

The overall objective of this paper is to contribute with knowledge of how learning artefacts can support both students, in taking more informed actions in becoming a professional engineer, and teachers, in design of relevant teaching and learning activities. This study is done as part of an on-going CDIO implementation, involving change of educational culture for leaders, teachers and students. For leaders and teachers, this involves a challenge to convert the CDIO intentions, into practical tools and everyday teaching and learning activities that in the end have only one overall objective: to support student learning. The current study included prototyping the learning artefact ‘IDE competence profile’ in teaching and learning activities and exploring how this contributed in strengthening students’ self-awareness of professional ID engineer identity, and in both students and teachers taking more informed actions during an introductory program course. The learning artefact contributed to teachers’ and students’ understanding of the professional ID engineering role, and also to more informed, self-directed actions during the course. In this paper we propose that learning artefacts not only support students’ self-awareness and guide their actions, but also help teachers in creating learning experiences that contribute to students’ understanding of the professional engineering role and thereby contributing in taking steps for change of the educational culture.

KEYWORDS

Strategic pedagogic development, artefacts, self-regulated learning, competences, objects of learning, professional role, CDIO standards 1-4

INTRODUCTION

The focus of this paper is learning artefacts, intended to support self-regulated learning strategies, towards personal, interpersonal and system building competences. In Sweden, programme objectives stated on a national level intend to steer higher education through directing its outcomes. However, a starting point in this paper is that policy descriptions such as formal programme objectives has weak manifestation in teaching practices, and thus fail to support teacher and student daily activities. An answer to this might be to establish clear measurable criteria, which restricts teachers’ or students’ influence and authority.
contrasting view is that programme objectives outlined at a national level neither can capture the complexity that exists in terms of conditions and realization in a teaching and learning practice, nor can they support or guide teacher and students’ activities (Wernberg, 2009). Gedda (2014) for example found that students easily could describe a course they had performed, but had much more difficulty in describing what they were learning through participating in a learning activity, or what they had learned after the course. For this reason, links between intended learning outcomes, and actual learnings can be said to not be prominent. There is hence a challenge to re-think the intent of a program in such ways that it can guide the teaching and learning practice. Intended learning outcomes in higher education can also be defined as intentions, intended objects of learning, learning opportunities such as activities and assignments that constitutes the enacted objects of learning, and outcomes, what students actually learn, as the lived objects of learning (Wernberg, 2009). In our view, the differences is that intentions often are formulated as ILOs students should demonstrate, which may be judged as right or wrong, whereas actual understanding is created within a context, a learning space, in which both students and teachers enact the learning experience. In the current study we explore how learning artefacts can guide enacted objects of learning, and support Industrial design engineering (IDE) students in becoming professional engineers. Drawing on theories of strategic pedagogical development, self-regulated learning and design of artefacts, we in this paper describe the design and implementation of a learning artefact, with the intent to support both students’ learning strategies and teachers’ teaching practices, as well as the intentions of CDIO.

**SELF-REGULATED LEARNING**

One of the most fundamental questions in higher education deals with how students learn and become skilled professionals. One aspect of this is described as strategies of surface vs. deep approach to learning (c.f. Marton & Säljö, 1976). This can be summarized as reproducing vs. understanding materials. Such learning strategies are not individual constructions, but depends on both students’ and teachers’ prior experiences that contributes to a educational culture, that is, how the student interprets requirements and answers to the perceived meanings in the learning environment (Gibbs, Knapper & Piccinin, 2009; Prosser & Trigwell, 1999). Self-regulated learning can exist with different strategies, but influence, as we understand it, not necessarily the quality of learning. However, Gibbs et al. state that an educational culture that favours students developing their own meanings, are more likely to result in higher quality of learning. Self-regulated learning should not only be the student’s responsibility, as it involves how teachers interact with students in learning activities and influence how education is organized and operated (Zimmerman, 1990). In this perspective, the focus should shift from analysing an individual student's learning ability, to what can support students' developing independent learning strategies in form of e.g. feedback, motivation, personal responsibility and self-awareness of academic achievements. Self-regulating students, in contrast to some of their peers, actively seek information about what is required to do and learn to master a task or a subject. When they face challenges, such as confused teachers, difficult concepts or texts, or other more or less poor study conditions, they will find a way to get the job done. Self-regulating students learn through a fairly systematic and controlled learning process, because they acknowledge that their performance is worth the effort (Pressley, Borkwski & Schneider, 1989). The strategies that
self-regulating students adopt support them in setting goals and continuously self-evaluate their performance, giving them greater opportunity to control their learning progression, compared to those students that doesn’t adopt such strategies (Zimmerman, 1990). In line with this is Osberg and Biesta’s (2008) argument of an alternative to the dichotomy of "unguided learning" versus "planned inculturation" in the concept of ‘space of emergence’. This involves to allow space for explorations of intentions, through representations and actions. It requires an educational culture enabling teachers and students to take own initiative and discuss each other's understanding and expressions. Such space of emergence contributes in promoting self-regulated learning through an active engagement in meaningful discussions, rather than promoting meaning transfer from teacher to student. This is supported through an understanding of professional qualifications, support for self-evaluation, encouragement of dialogues between teachers and students, contributions to motivation and self-esteem, and to continually provide opportunities for high-quality feedback (Hattie, 2008). When teachers provide feedback to students, they should in Osberg and Biesta’s view be ready to flexibly interpret student use of resources: what they have thought and acted on, rather than judging a specific outcome as right or wrong. In such educational cultures, it is more likely that students’ experience a return on investment, and that they can adopt self-regulated learning strategies. In up-coming sections, we discuss design of learning artefacts to support self-regulated learning.

DESIGN OF LEARNING ARTEFACTS

In general, the concept of artefacts can be described as objects that are intentionally designed. In a teaching practice there are a variety of designed artefacts such as whiteboards and projection screens. Objects designed to support a learning activity, i.e. with the intention of guiding students discussion or actions in certain ways, can be described as learning artefacts. A relevant question in this respect can therefore be how artefacts can be designed to enhance learning. Ideally artefacts are objects that embodies designers’ contextual knowledge and experience, resulting in value-creating solutions. Ehn (2008) for example describes that artefacts can be seen both as products that provide users with solutions to needs and access to certain features, and as things that contributes in change of user behaviour and thus opens up new ways of thinking and acting. In this view, a central part in the design of an artefact is to create connections, so-called alignments, which support a specific intended use, but also opens up completely new ways of thinking and acting. Artefact's ability to support alignment in a teaching and learning practice is what interests us in the current learning experiment. A challenge in design of artefacts for learning is however that they actually are implemented and used. Cuban (1986) for example argues that no matter how important an object, a tool, a particular technique or intervention may seem, teachers must see the value and how it can support them or their students, otherwise the artefact may never be meaningfully implemented and used. Artefacts can be affordances to action, i.e. support meaningful discussions of the overall learning objectives and/or possible actions to take, but they might as well limit the scope if they are not experienced as meaningful (e.g. Wenger, 2008; Trowler, 2008). Affordance is for this reason created in the activities in which the artefact is used or discussed, when the artefact supports or realizes the participant's intentions. Trowler (2008) for example describes that artefacts can be imbued with skills, means to reach certain goals, which means that students' overall performance with the artefact improves, whether or not there is any other change in the
individual ability. Such artefacts should be designed to be able to be abstracted from a particular context, and be able to move between different practices, and yet be interpreted for practical use. This can be labelled as a ‘boundary object’ (Star & Grisemeier, 1989; Bowker & Star, 1999; Star, 2010), which are intended to help increase the capacity of an idea, theory or practice, by exceeding culturally defined boundaries, such as support in and between knowledge areas and/or toward the current teaching and learning practice. A boundary object does not necessarily mean consensus in the teaching and learning practice, Star (2010) emphasizes that boundary objects should contribute to coordination and direction, without necessary stating what to do, allowing a user to interpret his or her own understanding from the local practice, which in turn can be reinterpreted in a larger collective activity between practitioners. Boundary objects allow different practices to be linked together, as individuals and groups can reach mutual understanding on a common task, without being forced to agree on how it should be performed (Wenger, 2008). A learning artefact that support an overall understanding of the main educational objectives, can be used by teachers and students in different ways, while their performance still improves.

THE IDE LEARNING EXPERIMENT

Until now in this text, we have laid the foundation and presented some tools with the aim of better understanding how intentions can be built into learning artefacts, be perceived as less abstract, and support meaningful interactions between students, teachers and educational leaders. The following sections includes an overview of the IDE learning experiment, outlined as how the learning artefact was conceived, designed and implemented, and how we plan to operate its use.

Conceive

The context of the current study is an on-going CDIO implementation at Luleå University of Technology (LTU), Sweden, in which Industrial Design Engineering (IDE) is one of the pilot programs. Before the current CDIO implementation, students perceived the courses in the IDE program as separate parts without relating to the IDE context, and without a constructively aligned curriculum. For this reason, several activities were initiated, among them educating teachers in CDIO standards, as well as discussions of the intent of the IDE education, and how teaching and learning activities better could contribute to the intentions of CDIO. A result of these preliminary activities was the development of a 15 credits introductory course during the first semester. The course was set-up for the around 80-90 first year IDE students, from different backgrounds, experience, age, and from various residencies in Sweden. The difference between upper secondary education and higher education is for some of these students huge, and it is quite common that the first university semester includes a search of identity in the IDE context. The course should be teaching effective, and relevant and inspirational to students, retaining them in the IDE program and profession. This however required a transformation of the educational culture, from the idea of one course - one teacher, with his or her own idea of the contribution it would provide to students’ learning, into what is described as “an integrated approach of identifying students’ learning needs and construct a sequence of learning experiences to meet them” (Crawley et al., 2014).
Design

A preliminary study, consisting of interviews, focus groups and discussions with both educational leaders, teachers and students at the program, indicated a need to support the understanding of both the IDE professional context and the CDIO approach. This resulted in the design of the artefact ‘competence profile’, developed in a sequence of iterative steps through participation of teachers, students, and alumni. The artefact is in itself a visualisation of eight central IDE competencies, including a scale from 1-5 illustrating progression of each competence (see Wikberg Nilsson & Törlind, 2016). In the introductory course, specific learning activities were developed, including activities intended to explore the IDE profession-specific knowledge and the characteristics of personal, interpersonal, and product, process, and system building skills needed for an ID engineer, see Figure 1.

![Diagram of Competence Profile](image)

Figure 1. Illustrate the learning artefact ‘competence profile’ in use in a self-assessment activity during the course.
Implement
The course design for the 2016 autumn semester included a number of learning activities,
some implicitly, and other more explicitly linked to the learning artefact. Table 1 outline the
activities that were directly linked to the artefact.
Table 1. Outline of the activities in which the learning artefact was used.
Course
introduction

The course introduction included a learning activity in which competences
for an IDE engineer were discussed, and the students reflected on which
competencies that can be central in the role of an industrial design
engineer. The concepts were then discussed, and teachers and students
agreed on descriptions in the form of 8 competencies. The students
thereafter valued their own perceived current competence in the different
sections.

Self-evaluation

On five occasions during the course, each after a specific learning activity
in which the students had a conceive-design-implement-operate learning
experience, the students performed self-evaluation of their individual
progression of the 8 competencies, see Figure 1. The students were
asked to describe:
§ Actions: a description of what the student have done to develop the
competence
§ Thoughts and emotions: a description of how the student
experienced the learning activity
§ Progress: a description of how the student regard his/her own
progression of the competence
§ Self-assessment: on a scale of 1-5, how the student value him or
herself for each of the 8 competences

Course end

The end of the course included a meta-reflection of the competences the
students experienced they had developed, as a result of learning
activities, actions and interactions, feedback and self-assessment.

Operate
The overall idea of the learning artefact ‘competence profile’ is that it shall be implemented in
various ways through-out the IDE program, and that both students and teachers understand
how learning activities can contribute to a progression of the competencies, in a continuous
process of conceiving, designing, implementing and operating in program courses. This is
however not the case today, as more work needs to be done about the learning artefact itself,
and of how it should be implemented and operated in the IDE program.

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OUTCOMES

The empirical data from the current learning experiment were gathered from multiple sources in the form of reviews of the submitted student self-evaluations, observations of how the artefacts were implemented and used during learning activities, and interviews with students and teachers. An analysis of the students’ submitted self-evaluations during the course illustrated that the artefact contributed to greater self-awareness and more deliberate actions taken. The students' understanding of their own competencies and how they progressed in the different teaching and learning activities evolved during the course. The course teachers also noticed that students spontaneously discussed the competencies and reflected on what they needed to do more or less of, in order to progress. This can also be seen in the students’ self-evaluations throughout the course, which fluctuated from being cautious in the beginning, to becoming more optimistic of own capabilities during and towards the end of the course. In this case, the learning artefact contributed to the students’ understanding on what they were intended to learn, what they actually learned, and what they did not quite master yet, and how they planned to act before the upcoming assignments. An interesting aspect in several of the self-evaluations is that the students describe what they need to develop, not what the teacher should "give" them, or what they will "receive" in upcoming learning activities and/or courses. This indicates self-awareness and might be a first step towards a self-regulated learning strategy. The course participants were first-year students. This is significant in terms of the artefacts’ contribution in transforming mind-sets: from completing a course or an assignment, to acknowledging what is required in their future professional practice. The artefact hence seems to have contributed to a meta-reflection of what is required in the IDE professional practice and in the learning process as is illustrated in the following citation:

"To skip the moments you experience as boring, tedious or challenging, would make it difficult to develop and learn something new. It would in a larger context mean that you become very narrow in your professional capacity and the tasks you can undertake, or for that matter, are offered. I think that struggling through even tough tasks, not only will allow me to come out on the other side as a more knowledgeable and multifaceted industrial design engineer, but also as a happier and stronger person. "

(Student – self-evaluation HT2016 authors’ translation)

An intent of the current learning experiment was that the artefact would support a focus on intents of teaching and learning activities, informed actions and students’ understanding of what they actually had learned. The learning artefact provided greater understanding of what is required of a professional ID engineer. The learning activities provided experience of some of these requirements, and thus a better understanding of what the competences actually are about. This can be seen in the following citations from a student self-evaluation, regarding the competence problem solving:

"Solving problems have been recurring throughout the course, and the most important part of the final project. Because of my previous experience of technical education my skills in problem solving was more or less developed, but it was only a theoretical understanding. Now, my problem solving skills has been put into practical use, and I think this is the skill that I have developed the most, at the same time as I experience it as the most important part of a technical education." 

(Student – reflection HT2016 authors’ translation)
The use of the artefact varied between the different learning activities. All of the participants contributed in the introductory discussion of competences, and the role of an ID engineer, and the following self-assessment activity, and about 9/10 participated in the final reflection on the learning experiences. About 2/3 of the participants took advantage of the five non-graded self-evaluation reflections during the course. The course teachers for this reason recognise that the learning activities need to be developed in up-coming courses, since some of the students saw it as an extra assignment that did not give them anything in return. According to the teachers, the learning activities with the artefact contributed to a change of mind-set, by supporting students in explorations and experimentations, rather than completing single course assignments. They consider the learning artefact relevant in the on-going CDIO implementation.

**DISCUSSION**

The overall objective of this paper is to contribute with knowledge of how learning artefacts can support both students, in taking more informed actions in becoming a professional engineer, and teachers, in design of relevant teaching and learning activities.

Based on the current learning experiment we acknowledge the learning artefact's implementation to have contributed to a focus on the role and competence of a professional ID engineer. Furthermore, artefact's role in influencing the educational culture is rarely discussed. With this study we hence made one contribution to the development of knowledge about the role and use of learning artefacts to support the transformation of a strategic intent, i.e. implementation of CDIO standards, to some steps of change in the IDE teaching and learning practice. To fully understand the role and relevance an artefact can have in influencing an educational culture, and the teaching and learning experiences, more studies, and implementation in various learning activities are needed. One option could be to develop a ‘learning framework’ for students’ competence advancement, in the form of e.g. a portfolio system. An important aspect is to integrate both students and teachers in the implementation, and that they see some kind of return on investment as a result of changing their teaching and learning practice. We consider the participants in the current study to have changed mindsets about both teaching and learning activities. The learning artefact contributed in encouraging a learning space, and served as a boundary object for discussing, and constantly returning to, the question of why we should do the things that we do in the IDE program. Students construct understanding of what is needed for a professional engineering role based on both explicit and implicit information, and a relatively small strategic change that contributes to their understanding of that role can improve their performance. The learning artefact promoted teachers and students' interactions, and gave both students and teachers support for independent informed actions. A starting point in this work was the challenge of transforming intentions and objectives into daily teaching and learning activities. If we can support leaders, teachers and students in better understanding the intentions of CDIO and the professional role through learning artefacts, then we can say that we have transformed the educational culture.
CONCLUSION

In summary, the learning artefact ‘competence profile’ and the previously described teaching and learning activities in which it has been implemented, we propose contributes to:

- Addressing CDIO standard 1, by clarifying and developing understanding of the IDE context of conceiving, designing, implementing, and operating products, processes and systems, among both teachers and students. Understanding of context and goals enhances the possibility for more students to adopt a self-regulated learning strategy.
- Addressing CDIO standard 2, by articulating essential IDE skills, and continuously discussing how these competences can progress through the synergy of integrating skills and subject knowledge.
- Addressing CDIO standard 3, by creating a ‘boundary object’ that supports teachers in integrating and constructively aligning different skills and subject knowledge towards the main purpose of engineering education.
- Addressing CDIO standard 4, by providing teachers and students with a structured framework for engineering practice and through that supporting the progression of learning experiences into operative competences.

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WHAT MAKES STUDENTS LEARN FOR LIFE

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ABSTRACT

As a master student, Jakupovic, the first author explored if and how computer science (CS) education may be up-to-date when the computer engineering area is such a moving target. Jakupovic interviewed former students, now working as programmers or project managers in industry, and found the following themes: The education laid the foundation for the programmers’ careers, but the transition from school to industry was rather difficult, and furthermore, what was taught, and expected by industry, did not correspond to students’ expectations of what to learn at the university.

In this study, we use these interviews to discuss the following questions: How can we make the transition into worklife smoother? How can we motivate students that what we are teaching is not outdated and obsolete? There are many studies on motivation, and especially using CDIO-courses as a motivating factor – how can these studies together with our study enhance CS engineering education?

The students speak about specific content they learned, the theory-practice gap and how teachers either teach or facilitate students’ learning. They also reflect on the fact that they, prior to the interviews, had not realized that the university courses had made such an impact on their career.

KEYWORDS

Student expectations, Computer Science Education, Curriculum Development, CDIO Standards 2, 3, 4, 5, 8, 9, 10, 11

INTRODUCTION

One of the most striking findings in Jakupovic’s (2016) master thesis was that former students, now engineers in industry, acknowledged that the higher education gave the foundation they needed, and that it wasn’t as outdated as they thought it to be. Of course, one may argue that these findings were an effect of the interview, but since Jakupovic’s hypothesis, at the time, was that the education was outdated and he thus did not expect this result it is interesting and striking. In his master thesis, Jakupovic’s research questions dealt with students’ transitions from university studies to industry work, how to enhance Computer Science and Informatics (CSI) education and adapt the curriculum in order to produce...
industry ready individuals. He conducted interviews with former students now working in the industry, and teaching staff at the university. Students had no troubles finding a job in the industry, however, the transition to industry was not easy.

Findings obtained show that both students' expectations and university commitment to curriculum development play an important role. However, one of the findings was that students’ expectations of what CSI-companies do and need, seem not to be aligned to what industry expects. This study aims at reanalyzing the data from the interviews and relate the results to other studies on students’ expectations and motivation. Prior studies on students’ expectations have mainly concentrated on enrollment and retention (Sahami et al., 2010, Klawe and Schneiderman 2005, Langan, Dunleavy, and Fielding, 2013), and studies on factors leading to study success (e.g. Tynjälä et al. 2005). More recent studies on students' expectations have dealt with how students develop their identity as computer science (CS) majors, or CS Engineers (Peters, 2014, Kinnunen et al. 2016). These studies have shown what students expect CS studies to contain, and what students believe their worklife will be like. They have focused on CS specific factors, such as “what CS-related knowledge and skills the students most relate to and what aspects of CS they perceive as relevant with respect to not only their previous experiences but also their envisioned future, trajectories and goals” (Kinnunen et al. 2016, p.4).

PURPOSE

The purpose of this paper is to start at the other end of the story, to study what former students, now working in industry, tell about their former studies, the expectations they recall about their envisioned future, and possibly how these expectations were treated. Our focus in this paper is to study the transition from higher education to industry, how it may become smoother and how to motivate students that what we are teaching is not outdated and obsolete.

By reanalyzing the interview data asking a new research question (not asked in the interviews), we hope to get new insights:

How can engineering schools, from this study, learn to bridge the gap between what students believe CSI studies should teach and what industry wants students to learn?

This paper is first in of a planned study on the same topic, following up with a similar interview research with teaching staff and industry representatives in the near future.

THEORETHICAL BACKGROUND

"Education is not preparation for life; education is life itself.”
-John Dewey

Engineering Education, as well as CS education have been, and still are, the subject of reform efforts (Froyd, Wankat and Smith 2012). One of the more recent is the CS2013 (ACM & IEEE Computer Society 2013), which builds on the curriculum designed by Sahami et al. (2010). This lead to a large boost of the number of applicants for a Computer Science undergraduate programme at Stanford University. A follow-up survey showed that 36% of the applicants applied only due to the curriculum change. These numbers imply that offering up
to date and modern education leads to higher attractiveness which results in a higher number of applicants. ACM & IEEE Computer Society (2013) state that students may misunderstand the nature of a programme/curriculum and that this may divert them from applying. They state that a common belief among students is that CS is all about programming and hence do not choose to apply. This is also confirmed in other studies such as Lewis et al (2010) and Kinnunen et al. (2016). Developing, and - more importantly - presenting curricula so that they show the diversity of aspects of CS may assure that students get a broader picture what CS studies are about. The mismatch between student expectations and the offered curriculum will both lead to students not enrolling at all and to students dropping out (Kinnunen et al., 2016). According to Jakupovic (2016), there is an obvious problem with students having wrong or unknown expectations when approaching university studies, since this leads to them being either unprepared for certain courses or unsatisfied with the knowledge offered within the particular program. One of the aspects debated throughout history is the theory/practice-divide Malmberg (2007). This is also reflected in the studies by both Peters (2014) and Lewis et al. (2010), who claim that the students expect to learn programming just by practice, whereas the teachers try to make the students learn also the theory. The gap between students’ expectations and teacher’s views are in some cases closing, but in other aspects widening, according to Lewis et al. (2010). They discuss the gaps and how they change throughout the education, but concludes with this being a challenge. Peters et al. (2014) are engaged in a longitudinal study on how expectations and attitudes change during the whole education, as a change in students’ identity.

Although the CDIO initiative has tried to meet some of these challenges by aligning education to learning outcomes expected by industry, it seems that the challenge to convey these intended learning outcomes is still in need of reform. Some basic examples of how to enhance motivation are given in table 6.1 in Crawley et al. (2008) and some of them tightly connected to this paper are:

- **Set clear intended learning outcomes relevant to engineering practice.**
- **Develop teaching activities and assessment tasks that help students reach the intended learning outcomes.**
- **Focus on deep working knowledge of basic concepts and provide connections to engineering practice.**
- **Design learning activities with built-in interaction.**

Are these criteria met in CS education? And, if so, are they perceived by the students?

**APPROACH**

We have built our investigation semi-structured interviews (Kvale 2014). In such, it is very important to design the interviews in a way where the interviewees themselves could fully express themselves. The amount of data for analysis was directly related to the interview length. Therefore, we made notes during transcribing to catch the data we found meaningful. Thus, we eliminated a large amount of data that we found unrelated to the topic, hence making the analysis more directed. We verified the data by determining validity, reliability and generalizability. Guba & Lincoln (1989) offer several ways to ensure quality of data and they
are confirmability, dependability, credibility and transferability but since our data came directly from the source we can only assume it is dependable and credible.

We held interviews with seven former students of Jönköping School of Engineering, now engineers in the industry. The interviews were afterwards transcribed verbatim for easier usage of collected data. This interview research was conducted in seven stages as proposed by Kvale (2014):

1. **Thematizing an interview project** – Decided upon who to interview, what we aim to collect through interviewing and how to proceed after collecting the data.

2. **Designing** – What information we want, and what topics would lead the interviewee towards answering them. This step directly impacts the results.

3. **Interviewing** – Guba & Lincoln (1981) stated that *the interview is but an instrument*, which would make the interviewer the user.

4. **Transcribing** – Often considered the straight forward part of the approach, where audio/video data is transferred into digital form for easier use.

5. **Analyzing** – Sewell (1998) suggests making data meaningful before we proceed with analyzing since that will allow us to work with less, but more valuable, data. While conducting the analysis we started to recognize that certain themes were present.

6. **Verifying** – In order to verify traditional research terms, Sewell (1998) states that you need to determine the validity, reliability and generalizability. We decided to verify the data during the interview session by asking the interviewee to confirm our understanding of the matter.

7. **Reporting** – The report must meet some accepted scientific criteria, ethical standards and be readable and usable for the user (Sewell 1998).

After completing these seven stages we had reasonable amount of data to proceed with concluding and discussing our research. We built an argument based on the themes captured in the interviews and further suggested adequate CDIO Standards as possible supporters in contributing and/or solving certain problems. The findings, discussion and conclusion will be presented in the upcoming Results section.

**PRESENTATION OF INTERVIEWEES**

Interviews were held with 7 former students from Jönköping School of Engineering, now working in companies within the CSI field. They have been working in industry two or less than two years after finishing their degree.

For ethical reasons, in line with an agreement with the interviewees we will not use names, gender and age whilst presenting them. They will be labeled as Interviewee_X and will be addressed in a masculine form. We have followed an inductive approach of analyzing and will present an interpretive analysis (Kvale 1996). For easier navigation, information about the interviewees, their background and current employment is presented in Table 1.
Table 1. Interviewee Background and Employment

<table>
<thead>
<tr>
<th>Name</th>
<th>Education</th>
<th>Employment</th>
<th>Employed for</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interviewee_1</td>
<td>Bachelor</td>
<td>Software Engineer</td>
<td>2 years</td>
</tr>
<tr>
<td>Interviewee_2</td>
<td>Bachelor</td>
<td>Software Engineer</td>
<td>2 years</td>
</tr>
<tr>
<td>Interviewee_3</td>
<td>Bachelor</td>
<td>Engineer and Server Admin</td>
<td>2 years</td>
</tr>
<tr>
<td>Interviewee_4</td>
<td>Bachelor</td>
<td>Software Engineer</td>
<td>2 years</td>
</tr>
<tr>
<td>Interviewee_5</td>
<td>Bachelor</td>
<td>Consultant (Software and Test Engineer)</td>
<td>2 years</td>
</tr>
<tr>
<td>Interviewee_6</td>
<td>Master</td>
<td>Software Engineer / Researcher</td>
<td>1 + 1 years</td>
</tr>
<tr>
<td>Interviewee_7</td>
<td>Master</td>
<td>Consultant (Software Engineer)</td>
<td>1 year</td>
</tr>
</tbody>
</table>

RESULTS

Our findings are presented using a theme-wise analysis, where the themes emerged from the collection of data. They are not exclusive categories, rather they are themes to be used in further analysis. The themes we identified are “Learn by doing”, “Solve or learn how to solve”, “University studies laid the foundation”, “Importance of Group Projects” and “Expectations from higher education”. Below we present these themes in more detail:

**Learn by doing**

Several interviewees state that it is upon themselves to learn by utilizing knowledge gained at the university and combining it with self-studies. That way they believe they’re investing in their studies and learning by doing is an important way to learn.

“The reason I learned so much, well I think I learned so much, is because of it takes a lot of time and effort from you, and not a lot of people want to invest in that; and I did. But even after I finished school I felt like I didn’t know enough, and I still do. After, well, 2 years, I still feel like I don’t know enough – and I’m probably going to think that all my life…” (Interviewee_3)

They also state that it is not the higher education per se, that will bring them to the next level, but rather their own involvement and will to grow. This also helps in the transition into work-life.

“Since I took responsibility while studying, I was feeling kind of secure, I know I can do this but it wasn’t like, ‘I can do it and it’s very easy’. Because it
was still a big hill to climb, but due to my responsibilities during my studies I think that I adapted pretty quickly.” (Interviewee_4)

**Solve or learn how to solve**

The majority of interviewees mentioned the importance of learning how to do something rather than just doing it without understanding the core. They comment how some teachers believe they are helping by solving the task instead of directing and guiding them, yet letting them solve it on their own and therefore learn how and why it works.

“The WHY - I always believed that as long as you understand something, you can always make it work. Not enough classes had labs that worked like that; most of them want to check out the box and see that you’re done…” (Interviewee_3)

Understanding the why and how may differ from one student to another, but if the approach of teaching the why and how are not right then it is hard to expect that the students fully understand what is being taught.

“There was a huge gap (between knowledge with students) ... and that made it, for us newbies, really hard because we felt so bad... The problem is, that we get an assignment – where we should do this and that, and if we get stuck, the teachers sat down and coded it themselves and then – here’s the solution. And you don’t learn anything with that…” (Interviewee_5)

Teaching the why and how does not only depend on the competences of the teaching staff but also of sufficient background knowledge that the students have. The ability to utilize the theory and combine it with practice leads to learning the why and how.

“When you sit at home, if you don’t have the theory you’re sitting and working on something; sooner or later you’re going to get your application to work, but you don’t really know why. You don’t know what’s going on and in some areas, or in some businesses, THAT’S MOST IMPORTANT!” (Interviewee_7)

**University studies laid the foundation**

Although the interviewer held the hypothesis that the CS education most likely would be outdated, the interviewees, during the interviews turned from a rather negative view of their higher education, and realized that the university studies still had impact. Especially teaching of basics and laying the foundation for further development, was mentioned.

“Probably a great deal more than I think; I think much stuff is probably somewhere in the back of your head at least. There were good courses and bad courses, good courses I remember stuff, it taught me how to think in programming. A lot of that stuff is still there…” (Interviewee_1)

Interviewees also mentioned that it would have been beneficial to work in a specific programming language, but also realized that higher education would teach them basics – allowing them to continue and master a programming language of their choice.
“I think the only reason why I’m able to work at [Company Name] is because I really learned the basics good. So even though I did not learn any of the technologies I work with today, I did some basic stuff – but not deep stuff, and because I learned the basics, I understood everything that I did. And that I do, even though I haven’t had any prior experience.” (Interviewee_3)

Pears (2015) states that higher education is not only about learning various subjects, but also growing as an individual in many other aspects. One of the interviewees came up with the same conclusion during the interview, saying that higher education made him a different person, laying not only the foundation for professional development but also personal development.

“The education that came with this degree, this program at JTH, it improved – increased my knowledge, in a sense that it gave me more confidence, it provided theoretical background for various subjects.” (Interviewee_6)

After a couple of years in the industry, they claim that the impact of their studies is still present. In addition, even though some knowledge is lost, the rest has been utilized and built upon.

“Since I’m still green, less than one year out of school, everything I refer to is from the time at the university, or projects from home. It (referring to school) still has a great impact on me.” (Interviewee_7)

**Importance of Group Projects**

The importance of group work and projects is mentioned at many occasions. We noticed how the interviewees mostly work in teams at their industry workplace and they claimed that they benefited from group projects during their higher education studies.

“We had two courses that mainly focused on running and planning projects, and those were very good courses because then you tried out your wings at school…” (Interviewee_4)

Group projects ideally tend to recreate real-life environment to help students experience the real-world, how to handle problems that come their way, and most importantly how to interact and benefit from working together (Jakupovic, 2016).

“I’ve benefited from group assignments, particularly group work, interactive work with teachers and students, other students.” (Interviewee_7)

**Expectations from Higher Education**

The interviewees demonstrate different expectations depending on their background. Some have already knowledge about software engineering and thus had no trouble passing the courses, some of them therefore believing that the university studies contributed very little to their development. Others had no experience and felt like higher education did not provide enough basic knowledge, and they either looked for help via distance courses or invested a lot of effort in studying through practice. But they also sometimes show that they know very little what to expect, as is also described by Kinnunen et al. (2016)
“When I studied, we had the first year, where everyone went and then the second year you could choose whether to go web or hard programming. I’d guess I’d rather see it be even more specific, I want to maybe work Java or .NET… I went web, and I don’t know why I chose that, I didn’t get enough info, I don’t like web.” (Interviewee_2)

It is hard to expect that curricula can be developed to suit every student, some want more practice while others better cope with theory. This was also demonstrated by the answers, but that the interviewees also expected a balance between theoretical and practical studies and did it contribute.

“It would be wrong to have only practice, it should be the combination of both… but we should focus more on practice compared to theory because most students get into the industry, while only a couple continue with academics. There, the theory will help but you need to know how to do it practically…” (Interviewee_6)

The interviewees discussed that certain courses were not fulfilling the expectations and even that some lecturers did not convey learning. Some believe that the teachers were not engaged in their subjects, and also that universities should invest in the competence of their teaching staff.

“The university should be a mix of it, the theory and the practice. Some courses are better at it than others, some teachers are a lot better than others, mixing good lecturing with good lab assignments…” (Interviewee_7)

We noticed that, even though our university offers all the necessary information regarding programmes and courses, students rarely take upon themselves to read about what’s expected from them and what the program and courses offer. As one example they expect the masters level to be directly preparing for industry, rather than further academic studies.

“But at masters level, I think it should focus more on practical level as compared to more theoretical level.” (Interviewee 7)

Students may also think that university programs are outdated because advanced topics were not covered:

In technology yes because we work with proven technology and that’s very important in some areas but in other…in other areas and other aspects the university is perhaps ten years behind in education. You don’t see you know, how do you say? Artificial intelligence courses today that matches what some companies has already achieved. I mean self-driving cars okay, we have…we have experimented with some robots that navigate in a small hallway here but the algorithms are so bad, so it crashes into the walls after a couple of turns but a lot of companies have get…got self-driven cars on the roads. So they are light years or not light years, I shouldn’t say, cause that’s a measure of distance not time, but they are many years ahead.
DISCUSSION

Both the transition into university, from high school, and the transition into work-life are difficult, and the expectations are often not in accordance with what the students meet. Kinnunen et al. (2016) discuss this in terms of short- and long-term expectations. Having no, or little experience of programming before entering university makes choices within the education difficult. Furthermore, it may take time before they study efficiently, e.g. interviewee 7 mentions that it took a long time before he started to study, not only to pass the courses, but to learn by practicing. Students who knew what to expect from higher education were better prepared and they had a more serious approach towards studies. They embraced the knowledge presented at the university and used it as a foundation to build on. By investing additional time in their homework, project work and studies, resulted in much better results and the accomplishment of self-set goals. On the other hand, some students that had earlier experience with computer science, felt they were not challenged, which resulted in them being either, uninterested and missing some valuable education or not following at all and therefore not comprehending.

A common pattern with the interviewees was to start off rather negative about their experience with higher education, in accordance with the hypothesis of the interviewer, but, as the interview continued, they concluded that they do use knowledge obtained at the university; then also followed up with constructive comments for both staff and other fellow students. One suggestion was to stimulate the teachers to engage in their subjects, another to use alumni in the courses to bring up-to-date technology into the courses.

When asked about the overall transition from higher education to industry their experiences differed quite a bit. It was obvious that those that had industry placement during their internship course and thesis work found a job position and adapted to the industry tempo much easier. Even though some had trouble finding a job right away, many of the interviewees either begun working straight out of university or shortly after. They all confirmed the importance of internship courses and writing thesis work with companies.

CONCLUSION

This interview research shows that former students, now computer science engineers in the industry, still reflect on higher education. Some acknowledge that they often use knowledge acquired through higher education while others state that it has laid the foundation, but that they really started learning when they started working. The biggest impact theoretical studies provide are the guidelines and basis for students to endure any obstacles set upon them (Jakupovic, 2016).

Our findings are also highlighting the findings from Kinnunen et al. (2016) that students often have rather narrow expectations of what CS studies are about, but when they reflect on their studies they realize that they have a much broader education, including e.g. project skills they need in industry.

Expectations vary from student to student but it is in best interest for the university and the student to understand and meet those expectations. This can only be accomplished through mutual engagement. The university needs to learn what students expect, as well as what industry expects. The latter is often done through conversations between university staff and industry representatives, and also through initiatives such as CDIO. However, this needs to
also be conveyed to the students: the university needs to explain not only the learning outcomes (the what and the how), but also the purpose of the learning outcomes (the why), set for each program. But we believe that it is also of crucial importance to learn more about the students’ expectations. If the students’ expectations differ from industry’s needs, this also needs to be addressed. This is a first attempt to do so, and similar studies are carried out (Peters, 2014, Kinnunen et al., 2016).

Longitudinal studies where the change in expectations are the focus will hopefully give further insight in both what it takes for students to understand what they need to learn and teachers what they need to convey beyond knowledge. This may result in an action research testing different ways of meeting these expectations and comparing the end results with a follow-up research of this kind.

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UNDERSTANDING FEEDBACK TO IMPROVE ONLINE COURSE DESIGN

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ABSTRACT

Quality feedback is a crucial ingredient in learning. The growth of online course delivery has altered the way that feedback is obtained and shared; new approaches have been and will be required to capture feedback, particularly informal types, in online environments. This paper examines the nature of feedback in the context of education and the creative approaches authors are currently exploring to capture and share it. A review of over 30 publications was conducted; techniques for sharing feedback from face-to-face to online delivery were mapped, and future trends for capturing informal feedback in the context of online environments were examined. Four main techniques for harnessing informal feedback in an online environment were found: increasing emphasis on formal feedback – particularly in the form of formative assessment; facilitating alternative “face-to-face” experiences; manual analysis of unstructured learner generated data; and automated: artificial intelligence, gamification, machine learning, smart platforms.

KEYWORDS

Feedback, Blended learning, Online learning, Standards: 2, 3, 7, 8, 10, 12.

INTRODUCTION

In any design process, a designer must understand the user’s needs, assess trade-offs and analyze alternatives based on a list of criteria. Instructional design also follows this process. In the case of traditional instructional design, content delivery alternatives are few, mainly consisting of face-to-face interactions such as lectures, tutorials or laboratories. The growth of the internet has substantially increased the number of delivery options, and hence the complexity of instructional design. With the growth of online delivery alternatives, possibilities range from face-to-face with minimal online components to full online delivery. Of particular note to this movement is the impact of user generated content (Web 2.0) which allows virtually any internet user anywhere in the world to generate and share lecture material on content sharing sites such as YouTube or Vimeo. In certain cases, the content is even organized into structured courses using free open-source educational platforms that include Moodle, Google Course Builder, and Open edX. There is little doubt that the growth of these technologies is changing the relationship between instructor and student, and in the process transforming the nature of education. Traditionally held views on feedback are challenged in these new educational regimes.
Literature has mainly been concerned with determining which combination of course delivery results in a change in student learning (Bowen, 2012; de Freitas, Morgan, & Gibson, 2015). While this is one approach that can offer insights into “better” course design, our objective here is different. Rather than attempt to determine a “best” or “better” blend for delivery, as this question has been discussed extensively in the literature, we attempt here to offer a comprehensive discussion of the historical role of feedback in learning and offer insights for future possibilities given recent technological advances. This paper attempts to generate an understanding of feedback from both the student and the instructor perspective and how technology may mediate this process.

**MOTIVATION**

The motivation for this paper came from an experiment conducted in 2013 in which all lecture content offered in a course taught by one of the authors was migrated to an online delivery platform. In the process, face-to-face student contact time was reduced by 66% and student questions were responded to using e-mail (Hugo, 2014). End-of-term course evaluations indicated that students desired increased contact time with the instructor. A possible explanation for this was that with decreased contact time students lost opportunities to formally express concerns about the material; another explanation was that students missed having engaging, informal interactions that they felt contributed to their learning. Our motivation for this paper was to better understand how student-student and student-instructor interactions in the form of feedback loops contribute to learning, and how these interactions are currently evolving with the rise of online learning. While the literature has emphasized the importance of formalized methods – particularly formative and summative assessment techniques to align on online course design, mediating and capturing informal interactions in the online space is a growing area of interest.

**OBJECTIVE**

The objective of this study was to gather and describe feedback methods that have historically been used by both instructors and students that contribute to engagement, motivation and depth of learning, and to map techniques researchers are implementing to harness feedback in online environments to improve course design.

**METHODOLOGY**

To better understand the ways that educators have harnessed feedback for course improvement and the ways students have used feedback to improve their learning, a literature review was conducted. A search was first conducted by combining variations of keywords such as “online learning” (e-learning, blended course, or MOOC design), and “feedback” in major databases including: IEEE Xplore, Scopus, and Web of Science. The primary concern for our preliminary research was to gather the methods authors have reported to give or gather feedback in online course design. Later iterations of research focused more heavily on reconciling those methods with the educational literature about feedback from a more philosophical standpoint. Reported methods were aggregated with our own experience as both users and designers of courses. Aggregated methods were then mapped against our established definition of feedback. The mapping was used to better
situate feedback techniques for the online space, identify gaps, and further focus next iterations of research.

BACKGROUND

Course design in tertiary education is subject to a number of constraints, including reduced funding levels and increasing enrollment (Bowen, 2012). As with any design process, user input and iterations are required to drive continuous improvement. Course design is particularly challenging because design cycles are long for a single course (approximately 4 months), and even longer for an entire degree program (up to 4 years). In design, feedback is a crucial tool that the designer can utilize to better understand whether a design is functioning as intended. Collection of quality feedback can be used to make improvements in subsequent generations of a product; instructors and students both use feedback to improve their work. In traditional course design, feedback has been used to improve learning experiences by gathering information obtained in formal (e.g. assessments) and informal (other verbal and non-verbal) interactions. Online platforms can inhibit the feedback process somewhat by altering the nature of informal interactions, but they also offer exciting opportunities to gather new types of feedback in the form of user data, such as watch minutes for videos (Hugo & Meikleham, 2016; Tisdell, 2016). Educators interested in improving online learning experiences can benefit from understanding the formal and informal feedback flows that exist in face-to-face environments, how these transfer to the online space, and what types of feedback unique to online spaces can be used to improve course design.

In his synthesis of over 500,000 educational studies, Hattie (2003) found that feedback was ranked first in the over 30 factors that impact the quality of student learning when using face-to-face delivery. Feedback not only plays a critical role in learning, but can also drive engagement and student motivation (Biggs & Tang, 2007; Gorham & Millette, 1997; Hattie, 2003), and it is critically important in establishing course climate (Ambrose, 2010). When harnessed properly, the feedback process is transformative for both student and instructor (Ambrose, 2010; Boud & Molloy, 2013). Recognizing that feedback has and will continue to play a critical role in student and instructor development, an ability to understand the complex nature of feedback in online course delivery is of critical importance. To guide this study, we have compiled the following research questions:

1. Is an emphasis on quality assessment enough to achieve quality learning?
2. Is formalized feedback the only feedback shared in a course?
3. How is informal feedback mediated by technology?

Is an emphasis on quality assessment enough to achieve quality learning?

Formative and summative assessments play a necessary but not sufficient role in achieving quality feedback in a classroom; we argue that recognizing this nuance is critical to developing meaningful online learning experiences. Biggs and Tang (2007), in their discussion on constructive alignment emphasize the importance of assessment design, but also discuss the general role that feedback plays in the learning journey. Nicol and Macfarlane-Dick (2006) examine the importance of “formative assessment and feedback” in developing self-regulated learning. In “How Learning Works,” Ambrose (2010, 121-152) dedicates an entire chapter to the importance of feedback, referring to the roles of “formative feedback” and “summative feedback” (139) in quality student learning. Countless authors
have described their approaches to assessing student learning (both formative and summative) in the spectrum of face-to-face to online environments (Asarta & Schmidt, 2016; Sarmento, 2011; Zhang, Dang, & Amer, 2016), but many more authors have recognized there is a broader role for feedback in the process.

**Is formalized feedback the only feedback shared in a course?**

Feedback is a communicative interaction that provides the sender information about how the receiver has received their message. In learning, it gives us an understanding of how students are doing at any point in time and in teaching it allows us to engage in reflective practices that improve course delivery. In education, feedback usually refers to a closed-loop process that formally benchmarks actions with desired learning outcomes; it can take verbal or non-verbal forms. In a more formalized view of feedback, the student and instructor co-navigate learning through a shared, directed dialogue (Boud & Molloy, 2013). This more formal view of feedback includes both formative and summative techniques (Ambrose, 2010). Many authors concentrate more specifically on formative and summative assessment techniques which work to validate successful uptake of learning outcomes. Like Ambrose (2010), we treat formative and summative assessment methods synonymously with formal feedback. We recognize the role of formative assessments to support the learning process with no or “low-stakes” grades (CMU Eberly Centre, 2015), and summative assessments to verify that overall constructive alignment is achieved through use of higher-stakes tasks. While formative and summative feedback remain an important area of constructive alignment (Biggs & Tang, 2007) for course designers, we argue that the growth of technology-mediated course delivery necessitates a broader discussion of feedback.

We propose that informal types of feedback also contribute to student learning, motivation, and engagement (Gorham & Millette, 1997; Hattie, 2003), but might not fall into the formalized definition described above. Here our definition of informal feedback is left intentionally broad. We do this to encompass traditional and newer forms of feedback, such as online user watch data, which do not fully align with the more formal definition of feedback above. A traditional example of informal feedback can be taken from a face-to-face lecture: an instructor is introducing a concept to a group of students and the students pull their eyebrows together in confusion. The instructor can (if they so choose) immediately interpret this feedback and pivot their delivery, or present an alternate example which might clarify the concept. Hattie (2003) refers to this as the “flexibility” of the expert instructor and discusses how flexibility is of critical importance to quality student learning.

The above example demonstrates how informal feedback can be an invaluable tool to both allow the instructor to improve their practice, and for students to gain an opportunity to improve their learning. Transactions like this may seem negligible, but we argue that their sum across an entire course can play a significant role in learning experiences (Hattie, 2003); these transactions appear to be missed by students (and instructors) if they are not somehow supplemented when courses are transferred online. These transactions have also historically played a critical role in establishing course climate, which has been shown to have significant repercussions on student learning (Ambrose, 2010). Student motivation also appears to be heavily linked to informal feedback cues (Gorham & Millette, 1997). Figure 1 illustrates our classification of feedback types for this discussion on student learning.
To avoid the appearance of a false dichotomy, we note that informal and formal feedback are probably not binary classifications. The purpose of presenting formal and informal feedback separately is not to functionally discretize feedback, but to highlight that a formalized view of feedback ignores some critical components that appear to contribute to learning experiences; we argue that this appears to be amplified in online learning environments.

**How is informal feedback mediated by technology?**

Traditional formal feedback mechanisms have historically transferred well to online delivery (Schuessler, Kolomenski, Bunker, & Perkins, 2016; Zhang et al., 2016), but informal feedback, for example body language and small talk, transfer less naturally to online environments (Jokinen, 2009). This phenomenon is depicted in Figure 2.

![Figure 2. Relationship between nature of contact and ability to share informal feedback.](image-url)
Peer feedback can also be shared formally (e.g. peer comments on an assignment) or informally (e.g. self-organized group study session), and peer feedback to the instructor about the student can be received both formally (e.g. peer evaluations) and informally (e.g. student visits during office hours). This loop broadly represents any interaction in the context of a course. In the ideal case this feedback loop is actively engaged throughout a learning experience, whether it is a lecture, lab or the sum of all activities in a course, Boud and Molloy (2013) refer to this as nested feedback. When this feedback loop breaks down, student learning and instructor reflective practice are compromised (Ambrose, 2010; Hattie, 2003).

What does the feedback loop look like with online delivery? Figure 4 depicts how the feedback loop between the student and instructor is mediated by a technological interface, such as a computer.

It is important to note that while a technological interface acts as a mediator for feedback, this does not necessarily imply less feedback overall, but rather a change in how feedback is shared. There is plenty of literature to demonstrate that formal feedback, in terms of formative and summative assessment, are mediated quite seamlessly through technological interfaces. Others have also examined the potential for gathering new forms of feedback previously not possible in a face-to-face environment (Goncher & Boles, 2016; Hugo & Meikleham, 2016; Tisdell, 2016). This is discussed more thoroughly in the following section.
RESULTS AND DISCUSSION

To-instructor and to-student feedback methods reported in the literature were gathered and classified according to type: from informal to formal. They were then placed on a continuum from “face-to-face” to “online” deliveries based on how the literature described their use, as shown in Figure 5.

Figure 5. Mapping of feedback types identified in the literature and their relation to delivery type.

Techniques located on the vertical axis were those which were found to have been easily translatable from face-to-face to online, usually with relatively few operations. Some feedback mechanisms were found to have counterparts that required significant design work and coordination to be translated from face-to-face to online, these were separated in the visual – for example, traditional and remote laboratories as described in Mikroyannidis et al., (2016).

As feedback type progressed from informal to formal, it was found that there was a decrease in the flexibility of the instructor to “pivot” their delivery in real-time based on the feedback they received. Similarly, students receiving more frequent informal and summative feedback appear to be in a better position to pivot their learning approaches to achieve learning goals within a course (Zhang et al., 2016). Ideally, for both the student and the instructor, feedback received throughout the course is cumulative (working from informal to summative) and is utilized in future iterations of teaching and learning. Shifting from face-to-face to online deliveries also reduces flexibility somewhat, because content may need to be re-created when a pivot is required; for example, a 10-minute online video clip that is unclear cannot be simply erased from the board and re-done in real-time as in a classroom, it must be re-filmed, edited, and uploaded.
The quadrant at the intersection of online delivery and informal feedback was left intentionally blank because its methodologies were less straightforward and warranted further discussion. Authors have come up with a number of creative approaches to bridge the informal feedback gap. The approaches reported in the literature can be categorized as follows; it is important to note that these categories are not necessarily mutually exclusive and were separated mainly for ease of discussion and emphasis on certain themes:

**Increasing emphasis on formal feedback – particularly formative**

One of the most common techniques used to supplement the lack of informal feedback was instructors placed more emphasis on gathering formal feedback. The feedback loop was apparently tightened by increasing the frequency of formal feedback, usually formative assessment. Authors reported using randomly generated multiple-attempt quizzes (sometimes as many as three per week), which helped to reduce knowledge gaps and allowed students and instructors to iterate on learning quickly (Zhang et al., 2016). De Freitas et al., (2015) reported that the simulator designed for their astronomy MOOC offered a valuable opportunity for students to validate learning before progressing onto successive modules. Zhang et al., (2016) required students to complete and submit “Cornell notes” – approximately 0.75-1 page per textbook page assigned for reading. Sharing of preparatory notes and findings with peers was required in a class and found to facilitate informal discussion and feedback between students (Gillet, Nguyen Ngoc, & Rekik, 2005). Nicol & Macfarlane-Dick (2006) also discuss how online assessments help to improve timeliness and relevance of feedback; they discuss the importance of relying on peer- and self-evaluation to regulate the learning process. A drawback of this methodology is that providing students with too much formal feedback can cause information overload (Ambrose 2010, 149) and result in a lack of direction for the student and instructor.

**Facilitating alternative “face-to-face” experiences**

Many authors have investigated the potential to implement blended approaches, offering project based and experiential learning in tandem with online deliveries (Delgado Kloos, Muñoz-Merino, Alario-Hoyos, Estévez Ayres, & Fernández-Panadero, 2015; Kloos, Muñoz-Merino, & Muñoz-Organero, 2015). CDIO institutions are particularly well positioned to make this type of adjustment given that project-based learning is integral to CDIO, and consequently institutions have both the necessary workspaces and experience required to make this type of transition. Courses offered with a blended delivery appear to offer a best-of-both-worlds approach, where online video lectures allow students to learn at their own pace and face-to-face lecture time is spent sharing informal and formal feedback (Schuessler et al., 2016). Courses restricted to only online delivery cannot benefit from structured face-to-face lecture time, but could offer video conferences (Koen, 2002), virtual office hours, or assign group projects which require students to interact with one another, thereby facilitating channels for feedback (Gillet et al., 2005). Online discussions are also used extensively, especially in the context of MOOCs to facilitate the peer-feedback process. It has been suggested that this method can rapidly become overwhelming for an instructor with large enrolment, so it is recommended the instructor only intervene in a small number of cases (Wautelet, Heng, Kolp, Penserini, & Poelmans, 2016). A drawback in this approach is that there are less clear pathways to scalability, particularly for assessment, which contradicts one of the key motivations for offering online courses in the first place (de Freitas et al., 2015). Authors have begun to examine the potential ways that automation can be used to solve this problem. These studies are discussed in the following sections.
Manual analysis of unstructured learner generated data

The potential to utilize unstructured user data to inform course design has been identified as an area of great promise (Wise, Cui, Jin, & Vytasek, 2017). Learning management systems are now formally designed to leave a “trail of data” (Dodero et al., 2017) that can be analyzed by the instructor. While a variety of user behaviours can be tracked in an online environment, Zacharis (2015) identified four main usage categories as significant predictors of success in an online environment: reading and posting messages, content creation contribution, quiz efforts, and files viewed. Whether site usage statistics alone can be used to predict success in a course is an ongoing debate (Gašević, Dawson, Rogers, & Gasevic, 2016); it is clear that the use of analytics can provide a valuable source of feedback to the instructor to inform pedagogical practices. Even non-learning oriented websites, such as Youtube.com, provide valuable analytics for educators: comments, likes, user retention, and watch minutes can all be used to gather feedback about student learning (Hugo & Meikleham, 2016; Sheridan, 2015; Tisdell, 2016; Topp, Helmer, & Ellaway, 2013). This data has been used as a proxy for informal feedback in an online environment (as identified in Figure 5). A major challenge with relying too heavily on analytics, as identified by Zacharis, (2015), is that while it may be relatively straight forward for the average instructor to gather data, finding “meaningful behaviour patterns and relationships that inform effective learning” can take considerable time and effort; there is considerable work to be done to facilitate this process. Another area of growth identified was that this feedback is rather one-directional in the short term (data goes only from student to instructor). Authors often report using current student usage data to inform “future” iterations of a course. Data analytics are “gold mines” (Wise et al., 2017) of feedback, but whether they are effective at closing the feedback loop between student and instructor in a given course remains unclear.

Automation: artificial intelligence, gamification, machine learning, smart platforms

If computers can be taught to understand what is pedagogically relevant, they can help to reduce the burden on instructors who are conducting manual data analyses by automating the process. In the spring of 2016, an artificial intelligence teaching assistant based on IBM’s Watson platform was successfully implemented in a course at Georgia Tech University (Gose, 2016). Gamification has also been used successfully to drive learner engagement in online courses (de Freitas et al., 2015); user-system (e.g. number of logins) and user-user interactions (e.g. discussions) are automatically tracked and quantified. Badges, levels and a variety of other rewards can be obtained based on site usage and interaction (Kuo & Chuang, 2016). Gamification appears to offer automatic feedback and reinforcement for students that are engaged in a course, which is somewhat of a gap given that engagement is a necessary but not sufficient requirement for deep learning (Biggs & Tang, 2007). Gamification could perhaps be better used to target pedagogical outcomes, rather than engagement metrics - machine learning would likely be required to fill this gap. For example, linguistics and machine learning are being used to mine and classify pedagogically relevant comment data (Goncher & Boles, 2016; Wise et al., 2017). Bassi et al., (2014) have suggested software agents as another area of opportunity in online education design due to their ability to perceive, operate autonomously, and reason. Smart platform design is another area of research that is specifically addressing the gap in nonverbal interactions in online interactions; this research has the potential to utilize machine learning to capture gesture and facial expression data (Jokinen, 2009). The growth in mobile devices and other augmented reality interfaces for course delivery (Halupka, 2012) could offer potentially new and exciting avenues for discovery in terms of mediating the feedback experience.
CONCLUSIONS

The literature indicates that while having strong formal channels of feedback are critical, they are not the only components required to achieve deep learning, reflective practice, and quality educational experiences. Informal feedback contributes to student engagement and establishment of course climate and can be taken for granted or ignored altogether when courses are transferred to the online environment. This paper presented four interventions authors have implemented to close the informal feedback loop in their online classrooms: increasing emphasis on formal feedback – particularly formative; facilitating alternative “face-to-face” experiences; manual analysis of unstructured learner generated data; and automated: artificial intelligence, gamification, machine learning, smart platforms.

The findings in the paper indicate that instructors who are considering implementing online components in their course deliveries should consider creative ways to open informal channels of feedback. Feedback mapping could be used by instructors in their course designs to identify the flow of feedback in their course and assessment design, thereby highlighting potential barriers to the sharing of quality feedback.
REFERENCES


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ADDRESSING DIVERSE LEARNING STYLES USING A DIGITAL LEARNING MANAGEMENT SYSTEM IN CLASSROOMS

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ABSTRACT
Consistent with the majority of provinces across Canada, the enrollment in senior level high school physics in Alberta has significantly lagged behind enrollment in commensurate chemistry and biology classes. Furthermore, there is significant gender disparity in respect of high school physics students; the majority of students are male. Since engineering faculties depend on these students for their enrollment, to foster diversity in their own student population, engineering outreach programs are often aimed at providing university led in-class presentations / demonstrations in K-12 classrooms. Although met with some anecdotal success, enrolment issues may be more effectively addressed by engineering academics if their efforts were directed toward providing research support in the evaluation of educational tools that may support high school teachers in delivering content themselves in a manner that appeals to their daily instructional needs and to the learning needs of the diverse student population.

An award winning digital learning management system (DLMS) developed by leading Canadian STEM not-for-profit organization is under investigation. This system is a personalized curriculum based hypermedia instructional tool for K-12 educators and students. Being digitally based, it has the potential for rapid integration into classrooms. The tool appeals to digital natives (students), and incorporates: mind mapping (discovery based learning), experts on call, gamification, all integrated through teacher views that produce dynamic project-based lesson plans. The system encourages an interdisciplinary approach that requires students to draw on multiple subject areas simultaneously to solve real world problems.

The global objective of this research program is to improve enrollment and outcomes in high school physics by the further analysis and development of the DLMS. In order to determine the gaps between learning styles and conventional teaching methods, and ultimately to inform physics specific DLMS development, this study will first present the results of attitudinal and learning style surveys that were conducted in local high schools that correlate learning style profiles, gender, and student attitudes towards physics. Some specifics of how the DLMS addresses these gaps is discussed along with the next phase of the research program.
KEYWORDS

Physics, learning styles, digital learning, diversity, outreach, student recruitment, gender, Standards 11, 12

INTRODUCTION

The 2013 Report on the Pan-Canadian Assessment of Science, Reading, and Mathematics (Council of Ministers of Education, Canada (CMEC), 2013) states that Alberta leads the nation for science performance among grade 8 students. Unfortunately, the majority of these early scientists are not choosing to take physics in high school; enrollment in senior level, high school physics in Alberta has significantly lagged in comparison to chemistry and biology. In 2010 (NSERC, 2010) the number of diploma exams completed in Alberta in physics was only 21% of the total diploma exams written in the major sciences. Furthermore, the enrollment of women in Alberta senior level physics classes has hovered around 38% between 2005 and 2010 (NSERC, 2010). Since a credit in senior physics is normally required for entrance into engineering programs across the country, it is a concern that engineering programs are losing students as a result of the decrease of students in high school senior level physics. Consequently, the potential for females entering into engineering is also reduced as only a fraction of that 38% will choose the vocation.

Some engineering faculties in Canada are re-evaluating the current entrance requirements and the subsequent ramifications of compromising the high-school physics prerequisite, considering instead to teach the content in university. In a more feasible and collaborative approach, engineering outreach programs aimed at providing supplementary content in K-12 classrooms have become common place in an effort to combat the problem. In such programs, university faculty and students provide curriculum-based demonstrations or career talks in K-12 classrooms. Although these programs are met with some anecdotal success, they do not globally address the daily issues associated with traditional teaching methods in K-12 classrooms.

Thayer School of Engineering at Dartmouth College reported a higher number of female engineering graduates than males in June 2016 (Dartmouth College, 2016). One significant shift in the programming at Thayer was that it started placing an emphasis on group-based projects in introductory classes. These classes were structured to let students understand why they were studying the course materials, which appealed to many of the females in the program. This approach is a departure from the traditionally linear way to teach these materials. Like the Dartmouth College example, enrollment issues may be better addressed by changing how Physics is taught in high school.

Studies have shown that physics is perceived as difficult and irrelevant (Cech, 2013), (Cumming, & Bain, 2006), contributing to the attrition of students who choose not to pursue engineering as a field of study. Studies have suggested that the traditional linear model used to teach physics is ineffectual and does not address the diverse learning styles of today’s students (Rockland, et al., 2010) or the differences in engagement between genders (Catsambis, 1995). As was indicated at Thayer School of Engineering, a more global approach to understanding the whole problem, relating the theory to the daily lives of most people, can affect an overall increase in the diversity of students pursuing physics and ultimately, engineering.
For this study, interested parties of engineering university academics, K-12 Science, Technology, Engineering, and Math (STEM) researchers have partnered in an attempt to positively impact high school physics enrollment and outcomes. Specifically, an evaluation of the correlations between learning style, gender and attitude towards physics is investigated in detail. The results of this study will be used to help develop physics modules for a Digital Learning Management System (DLMS) (MindFuel, 2017) and to explore its efficacy in increasing student outcomes in, and affinity towards physics. The DLMS is a hypermedia instructional tool developed for K-12 educators and students that will continue to evolve to meet the growing needs of educators as they, along with researchers, continue to pursue best practices in teaching and learning. The DLMS has been developed to accommodate multiple entry points for all students and educators, allowing for students of varied learning styles and differing abilities to achieve success on the platform. It has been developed by a leading Canadian STEM educational not-for-profit organization.

This paper first presents the results of attitudinal and learning style surveys that were conducted in local high schools. The researchers used the Felder-Silverman Index of Learning Styles (ILS) survey (Felder & Soloman, 2001), widely used in understanding the learning styles of engineering students at the post-secondary level. The analysis of the results will focus on correlating students learning styles with gender and attitude towards physics. The DLMS will then be presented and evaluated as a tool that has the potential to overcome some of the barriers students face in enrolling in and succeeding in physics. Conclusions will be drawn regarding the potential benefits of the use of the DLMS in K-12 classrooms. Finally, the ongoing research activities being conducted will be presented.

GENDER-BASED ATTITUDINAL INSIGHTS INTO PHYSICS

A group of high school students in grades 10–12 (n=186) were engaged to determine what correlations exist between their interest in physics, learning style, and gender. The students were given a multi-part survey to self-report on gender, respond to attitudinal questions towards physics and complete the ILS survey. The attitudinal survey included questions such as "physics is hard", "physics is interesting", "I see physics in my everyday life" and "physics leads to rewarding career choices". Students responded on a five-point scale, ranging from Strongly Agree to Strongly Disagree.
As shown in Figure 1, three distinct segments emerged from the attitudinal survey – physics fans, those indifferent towards physics and those not interested in physics. Gender disparity was evident between the physics fans and not interested group.

- Approximately 2:1 male to female ratio for pro-physics
- Approximately 4:1 female to male ratio were not interested in physics
- Moderately higher female to male ratio indifferent to physics

Data analysis was conducted on student responses to determine attitudinal segmentation resulting in the three segments. This is based on a k-means algorithm that tries to maximize differences amongst the segments, while minimizing the variance within each of the segments produced. Thus, it is not hierarchical, but rather multivariate “best fit.” The resulting segments range from Physic Fans, to a group that seems indifferent to it, and a group who obviously have no interest in physics.

The survey was divided into three sections. The first section established gender, grade and course enrollment; the second was a series of nine questions addressing attitudes toward physics and the third was the Felder Solomon Index of Learning Styles. The attitudinal questions were written to avoid introduction of bias. In future iterations of the research, the questions will be randomized to avoid any potential for gender bias to be introduced into the responses.

In several publications, research supported the findings that females were either not as interested in physics compared to their male counterparts or that they were dissuaded from pursuing it at a post-secondary level. (Checkly, 2010) (Ding & Harskamp, 2006) (Hasse, 2002) (Ivie, Cuzjko, & Stowe, 2001) (Robertson, 2006). Their findings suggest that various additional gender-related factors contribute to the lack of females in physics. These include gender imbalance in the classroom, a lack of female leadership in physics and gender difference in connecting physics to extracurricular physics activities (play) (Hasse, 2002). This paper focuses on the connection between learning style and gender as they relate to interest in physics; it should be noted that other influencing factors may also contribute to the gender disparity in physics engagement.
LEARNING STYLE RESULTS

Apart from the Felder-Silverman learning model (FSLM) (Felder & Silverman, 1988), numerous learning style models have been proposed (Kolb D., 1984), (Dunn & Dunn, 1978), (Myers I., 1962). All models classify students according to scales that are defined based on the way learners receive and process information. The FSLM incorporates some elements of the Myers-Briggs model and Kolb’s experiential learning model. The main reasoning for its selection in the DLMS evaluation is that it focuses on aspects of learning that are significant in engineering education.

The FSLM consists of four dimensions, each with two contrasting learning styles: Processing (Active/Reflective); Perception (Sensing/Intuitive); Input (Visual/Verbal); and Understanding (Sequential/Global). A summary of the learning styles is as follows:

- Active learners are those who learn by trying things out, enjoy working in groups. Reflective students learn by thinking things through, prefer working alone or with a single familiar partner.
- Sensing students are concrete thinkers, practical, oriented toward facts and procedures. Intuitive students are abstract thinkers, innovative, oriented toward theories and underlying meanings.
- Visual learners prefer visual representations of presented material, such as pictures, diagrams and flow charts. Verbal students prefer written and spoken explanations.
- Sequential learners demonstrate a linear thinking process, learning in small incremental steps. Global learners use a holistic thinking process, learn in large leaps.

Each of the 44 questions within the associated ILS survey is designed to place the learner’s preference within each of the four dimensions. Depending on the answers to the questions relating to a given dimension, the learner can be described as one with a strong, moderate, or mild preference for one learning style over the other within a given dimension.

There have been extensive studies (Zywno, 2003) (Felder & Spurlin, 2005) that have aimed at validating the survey, and there is also a great deal of published data (Felder & Spurlin, 2005) (Mansor & Ismail, 2012) (Kolmos & Egelund, 2008) from test studies done in universities. Results of studies have shown that learning preferences vary among students in different fields of study. Within the four dimensions, engineering students tend to have preferences for Active, Sensing, Visual, and Sequential learning styles (Felder & Spurlin, 2005).

Results of the physics fans’ and physics foes learning style profiles are compared to baseline engineering students’ data in Figure 2. The baseline engineering student data (Felder & Spurlin, 2005) is a compilation of the results from ILS surveys conducted by engineering students at ten different North American universities. It is interesting to note that results of the physics fans segment (n=71) demonstrated a strong correlation in all four dimensions to this Felder profile for engineering students. More significant differences exist between physics foes and engineering students. Of note, physics foes tend to be more active, more intuitive, and more sequential learners than physics fans or engineering students. The biggest differences between Physics Fans and those Not Interested in Physics are seen in the Sensing / Intuitive and Sequential/Global spectra. It is because of this disparity that the initial pilot of the DLMS with students will have a particular focus on activities and lesson plans that incorporate sensing and global approaches to learning.
Figure 2. Comparison of Felder's baseline profile for post-secondary engineering students to high school physics fans

The learning styles of the physics fans are broken down by gender and compared to the baseline Felder data in Figure 3. The chart suggests that on the whole the differences between the learning style profiles of male, female, and engineering students are not significant among physics fans. The largest difference in the profiles is that the female fans lean more towards sequential learning styles (as opposed to global) than the engineering students or male physics fans.

The learning styles of the physics foes are broken down by gender and compared to the baseline Felder data in Figure 4. Female physics foes are more Active, Visual, and Sequential than male counterparts and engineering students. Moreover, on the whole, female students tend to be more sequential learners than the male and engineering students, regardless of their preferences in physics.
Figure 4. Learning Styles of Physics Foes by Gender

Within the four dimensions, engineering students and physics fans tend to have preferences for Active, Sensing, Visual, and Sequential learning. This is in contrast to conventional instructional methods that tend to be more reflective (little room for active participation in lectures), intuitive (abstract theory delivered in symbols), and verbal (lecture delivery medium). These conventional instructional methods may not be addressing female learners that are less interested in physics who have an even stronger preference for active and visual learning than the others. This gap between the instructional methods and learning style preference in female students may be a contributing factor to the greater lack of interest in physics among female students than male students.

Although conventional instructional methods do address sequential learners, the lack of the big-picture emphasis often completely loses global learners. In order to address the mismatch between teaching methods and learning styles in university environments, Felder advocates a balanced approach to engineering education that incorporates experiential, active, collaborative, and student-centered learning (Felder & Spurlin, 2005) (Prince & Felder, R.M., 2006). This balanced approach to learning is of particular importance in the K-12 environment where students with diverse learning styles work together in classroom situations.

EVALUATION OF THE DLMS IN THE CONTEXT OF STUDENT LEARNING STYLES

Today’s K-12 students are digital natives, never having known a time where technology was not integrated as a key component of their daily lives. It is therefore imperative that digital engagement forms a part of students’ educational experiences, using its full capabilities to make content relevant and engaging. K-12 educational institutions are beginning to integrate such content and technologies into the classroom to achieve maximum learning impact. As technology enters the classroom in a more pervasive and consistent manner, digital tools have the potential for rapid integration. If developed and implemented thoughtfully such widespread adoption may serve to address some mismatches that may exist between teaching methods and learning styles.

The DLMS has been studied extensively, engaging a group of K-12 science teachers (n=87) to determine their needs and ensuring those needs were met throughout the development
phases. In addition, students (n=153) were surveyed to determine what barriers existed, that if removed could more fully engage them in science learning. The students reported that traditional teaching methods such as lectures and reading static materials was considered dull or boring and that conversely, the ability to participate in independent learning opportunities would be more engaging. In response to these studies, the DLMS was developed on the basis of the following intents:

- Multiple entry points for both students and educators to allow for varied learning styles and differing abilities to achieve success on the platform.
- Create meaningful learning spaces both in the digital realm as well as in hands-on, design based activities based on the constructivist (BSCS 5E Instructional Model) (BSCS, 2007) educational approach to lessons in which students are first engaged or “hooked”, then asked to explore-explain-elaborate-evaluate.
- Mastery learning (Kulik, Kulik, & Bangert-Drowns, 1990) in which student’s approach and progress through the material at an individualized pace that supports meaningful engagement in curricular concepts.
- Build the opportunity for collaborative group work involving multiple perspectives; virtually connect subject matter experts working in STEM careers with students in the classroom to foster engagement.
- Leverage social media to allow for STEM learning beyond the classroom environment and foster dialogue around STEM topics
- Usage of digital platform to create community and connect users in remote areas
- Position real-world problems to students for them to develop innovative solutions

The DLMS was evaluated by 87 teachers and their students throughout Canada and the United States. Participants were provided access to the platform and asked to deliver certain content, after which, they were asked to complete a survey. Feedback from the first phase of the DLMS has been positive. Teachers interacting with the DLMS have indicated that “[it] provided [teachers] with new ideas and ways to teach science content”, and that it “offered...students exposure to more career and real-life applications”. The customizable lesson plans, interactive live events, mind map exploration, and videos and games that comprise the DLMS were all identified as key benefits to using the DLMS for heightened student engagement. One teacher said that, with the DLMS, “students are learning about science through interaction on multiple levels, not just listening and taking notes.”

The DLMS strives to create a balanced learning experience in which students, regardless of their learning style preference, are engaged in activities that meet their needs. Highlights of the DLMS’s balanced approach to learning (as detailed in Singh, Sun, & Weber, 2016), are as follows:

- Active / Reflective - For active learners, the DLMS prompts students to work collaboratively in real-world activities. Through online games and videos, the DLMS also allows reflective learners to consume content at a personalized pace.
- Sensing / Intuitive - The DLMS combines multiple types of activities that are grounded in real-world scenarios so as to mimic both the logic-oriented, detailed nature of sensing leaners; however, the majority of content and lessons are geared towards the intuitive learner who takes a more holistic approach to learning.
- Visual / Verbal - One of the great advantages of the DLMS and its digital delivery of curriculum content is that with multimedia, visual and auditory learners can be simultaneously engaged.
• Global / Sequential - One of the defining elements of the DLMS is embedded in how digital resources can be browsed and viewed; The first is a sequential, linear “browse” capability that presents information in a progressively narrowed fashion. The second is termed the “mind map” and visually illustrates a holistic overview of the platform content that students can navigate based on category or keyword.

Ultimately, the DLMS provides a balanced approach to learning and addresses all the diverse learning preferences discussed in the Felder-Silverman ILS. As a result, it has the ability to create an environment where science (and specifically, physics) concepts can be absorbed and made relevant to K-12 students who are in the progression toward their career choices. The DLMS is based on a foundation of interdisciplinary learning and provides opportunities for students who are engaged in chemistry or biology to encounter physics concepts when engaging in the open-ended Project-Based Learning modules. (Singh, Sun, & Weber, 2016).

SUMMARY AND FUTURE RESEARCH

The Attitude, Gender and Learning Style study demonstrates multiple distinct issues. First, gender plays a difference in attitude towards physics with 54% of male respondents indicating a preference for physics while, conversely, only 25% of female participants indicated the same. Only 7% of males were not interested in physics and the remaining 39% indicated indifference toward the subject. For females, only 26% showed a lack of interest in physics, while 49% indicated an indifference.

Second, although using a small sample size, students within the physics fans, or pro-physics group (n=71), correlated significantly to the learning style profile of engineering students as represented by Felder. Finally, a significant difference between engagement and learning style is evident in the Sensing / Intuitive and Sequential / Global dimensions. This provides an opportunity for the DLMS to provide learning experiences that address these two dimensions.

Ongoing quantitative evaluations of the DLMS and how it may support diverse student needs at the K-12 level to foster interest in physics are moving forward. Currently, this includes creation of activities and lesson plans for the grade 10 physics module that incorporate the balanced approach advocated by Felder. Our focus will be to structure activities and lessons that meet the needs, in particular, of students who demonstrate a strong tendency toward the global and sensing learning styles. These two learning styles were identified as having the greatest disparity between Physics Fans and those Not Interested in Physics.

Initial feedback on the DLMS has been positive; however, as the DLMS attempts to engage students across an increasing span of grades and subjects, depth and breadth of content becomes a concern. In order to meet instructional needs, it will be important to ensure the lessons and activities, which are focused on addressing diverse learning styles, also meet curricular objectives for implementation in the classroom. The developers of the DLMS are considering adding the ILS to the platform. Students who complete the survey will receive a recommendation for how best to navigate and use the DLMS based on their personalized results, thus, improving the connection between learning style and student learning on the DLMS.
The aforementioned activities and lesson plans, in conjunction with the Attitude, Gender and Learning Style study are being introduced to a larger student body in the fall of 2017-18. The research findings from these evaluations will help to build understanding among students, teachers, and academics, and it is the authors’ aim to support and inform current best practices in education.

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BIOGRAPHICAL INFORMATION

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WORK-BASED LEARNING MODELS IN FRENCH ENGINEERING CURRICULA

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ABSTRACT

In the 90s, the French engineering education accreditation body introduced in its quality standards a compulsory internship period. Based on this national experience, this paper presents an in-depth background and description of the use of internships and apprenticeships models in French engineering education. The elements of analysis presented may provide some inputs to programme designers in other contexts. Thus, this paper proposes to extend the CDIO framework to systematically include Work-based Learning as integrated activities in educational programme, to better match industry requirements and student competency expectations as future engineers.

KEYWORDS


INTRODUCTION

From 2012 to 2015, the European Ministers of the European Higher Education Area (EHEA) gave as a priority for working “to improve employability, learning throughout life, the ability to problem solving, entrepreneurial skills, through enhanced cooperation with employers, especially for the development of training programs” [EU Bucharest Communiqué, 2012]. This formal recommendation applies to all Higher Educational Institutions (HEI) and fields and it has a special resonance for the training of engineers. Even more, Work-Based Learnings (WBL) are strongly supported in the EHEA for the period 2011-2020. The ministries in charge of Higher Education (HE) considered WBL as major tools to meeting the twin goals of improving individuals’ employability and increasing economic competitiveness [EU Bruges Communiqué, 2011]. Although there is now in European HE a global agreement
on these orientations and on the underlying competence approach, their concrete implementation -even in 2016- is highly variable depending on the countries and the institutions [Remaud, 2013]. In particular, because they sometimes conflict with the view of university professors on their missions. In the formal academic environment, it is acknowledged that the tension between real-practice skills and engineering disciplinary knowledge is hard to manage in curricula [Rouvrais, 2012]. Competences are context-dependent and should be developed in a technical environment, especially for future engineers. In traditional in-school engineering programmes, where integrated curricula supported by project-based learning methods (PjBL) may exist, industry partnerships are often in place, which may result in various intra- and extra-curricular activities, e.g. sponsoring of student activities, forums and seminars, lending equipment, teaching by company representatives, and particularly, internships in companies as part of the school curriculum. WBL relates to several models. Internships in research labs of the academic institution or capstone PjBL experiences with industrial partners are some examples, as analysed in [Einarson, 2016] with learning outcomes and assessment alignment.

In this regard of WBL integration, the French experience appears as peculiar, as linked with the -80 years-old- organisation of engineering studies. In 1934, the French Law tasked the national engineering accreditation body (CTI - Commission des Titres d'Ingénieur) with assessing the programmes of engineering education. The “titre d'ingénieur diplômé” (a Master’s degree in Engineering Science) is then awarded to students by the institutions accredited by CTI. CTI’s board membership comprises 50% of employers and professional engineers’ representatives and 50% of academia. It has a wide autonomy -without governmental interference- to define new standards and to enforce them in HE. From the CTI origins, French HE have been rather sensitive to the cooperation of employers and academia as a key factor for the training of engineers. But during the last three decades, many relationships have been developed between graduate engineering schools and companies, aiming at adapting the programmes to the needs of the job market. In the 90s, CTI introduced in its accreditation standards a compulsory internship period for all engineering programmes. Nowadays, a student cannot graduate if he/she has not validated his/her internship. At the time of writing, an internship in French engineering education, as a semester in a company during the curriculum, is valued between 24 credits to 30 ECTS (European Credit Transfer System).

French engineering education mainly relies on two WBL models: regular higher engineering education (HEE) at Master level and vocational education and training for engineers (VETE). In such a context, the focus of this paper is to recall the two main models of internship (HE-based) and apprenticeship (VET-based) in French engineering education in line with the CDIO framework reference models [Crawley et al., 2014]. The elements of analysis presented in the paper may thus provide some inputs to international CDIO collaborators or newcomers investigating to include WBL as integrated activities in their programmes so as to better bridge some gaps with industry requirements and CDIO skills. This analysis also provides some rationale to better meet intended outcomes for students. From then, the existing twelve CDIO reference models are put to the test in order to draft opportunities of reference model adaptation and ultimately improvement of the quality of HEE from various stakeholders’ viewpoints.

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4 Initially, only the private institutions were concerned, CTI mission was then extended to all institutions.
WORK-BASED LEARNING IN FRENCH ENGINEERING EDUCATION

WBL, as a key aspect of VET, is directly linked to its goal of helping learners acquire knowledge, skills and competences with direct relevance for the labour market [European Commission, 2016]. WBL has been extensively analysed in the literature. Two decades ago, Brennan and Little [Brennan and Little, 1996] showed that WBL is in the workplace, but, in certain conditions, it can also be in HE. They questioned the roles and responsibilities of individual employers and higher education in the continuing education and training of adults, and identified corresponding risks and problems. They produced a substantial literature review of progress made and issues raised in the field of WBL in HE. More recently, exploration on engineering students’ perceptions of developing practical competencies as experienced in their industrial placements has been studied in a CDIO context [Kamaluddin, 2015]. Nevertheless, there is still a widely-shared opinion among academia that WBL models would not have the same standing as general education or academic education and are often regarded as second-rate education, is that judging over?

Since two decades the situation has evolved in France and practice of WBL curriculum integration has been partially evaluated. In fact, many of WBL developments were supported by government-sponsored schemes the last years. More recently, Europe has set up many recommendations and practices in WBL for HE [European Commission, 2013]. In the context of engineering education, France has its particularities [Maury, 2012]. As recalled by Maury from the CEFI (Centre d’études sur les formations et l’emploi des ingénieurs) during an international CDIO meeting in France [Maury, 2012], among the five cultural keys which permit to understand French HE is “in France we love complexity and variety”. Industry partnerships and WBL models are French cultural keys, as in the following models of WBL:

- Internships for HE engineering students, which are “on-the-job training periods in companies (...) that are incorporated as a compulsory or optional element of programmes leading to formal qualifications” [European Commission, 2016];
- Apprenticeship for VET engineering students, which “formally combines and alternates company-based training with school-based education, and leads to nationally recognised qualification upon successful completion. (...) There is a contractual relationship between the employer and the apprentice, with the apprentice being paid for his/her work” [European Commission, 2016].

Internships and apprenticeships are usually considered and highly praised in the context of VET. Although the situation is very diverse in European countries, these WBL models are widely used for the levels 1 to 5 of the European Qualifications Frameworks (EQF). They are much less in use for the levels 6 (Bachelor) and 7 (Master) in several countries.

In France, full accredited engineering programmes are developed in traditional and highly selective Grandes Écoles (distinct from universities and supervised by Technical ministries, 25% of the engineering students, e.g. as at Mines Paris, IMT Atlantique), in private Grandes Écoles (25%, e.g. as at ECAM, ICAM, ESTP), in universities of technology (18%, e.g. as at UTC, UTT, INSA), and in university components (23%, e.g. as at Polytech), the other 9% being for professional and vocational education (e.g. as at CNAM, CESI) [Maury, 2012]. To exemplify the French diversity, two models of WBL are described in this paper, in two different institutional contexts, i.e. in a public Grande École (IMT Atlantique) and in a private Graduate School of Engineering (CESI), both institutions where ECTS are allocated to WBL as presented in Table 1:
Table 1. ECTS WBL credit ratio at an IMT Atlantique campus and CESI group for their two types of Master level programmes.

<table>
<thead>
<tr>
<th>Institution / WBL model at Master level</th>
<th>Last year internship (HE students in 3 years)</th>
<th>Apprenticeship over 3 years (VET students in 3 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMT Atlantique (Telecom Bretagne campus)</td>
<td>24 / 180 ECTS (215 students per year)</td>
<td>66 / 180 ECTS (40 students per year)</td>
</tr>
<tr>
<td>CESI Graduate</td>
<td>20 / 180 ECTS (250 students per year)</td>
<td>63 / 180 ECTS (1250 students per year)</td>
</tr>
</tbody>
</table>

*Internship WBL model in French Engineers’ curricula*

Far in the past (i.e. 1990), CTI considered and approved alternate study periods of engineering students in companies. At the turn of the XXth century, CTI introduced mandatory internships in all Master’s Degrees (“Ingénieur diplômé”). In the 2001 revised version of its frameworks standards, CTI considered 20 weeks of cumulated duration of internships as a minimum. In the 2016 version of its standards [CTI 2016], CTI states that “the aim of the training courses in the workplace for engineering students is to acquire technical, organizational and human skills”. A minimum of 26 weeks of internship is now required for all students during their 300 ECTS Engineer curriculum at Master level. This total duration can include [Remaud et al., 2010]:

- Operative internships: (“Stage ouvrier”) usually placed at the beginning of the engineering studies, for a short duration (less than one month). In these internships, the HE students need to perform a low-level (usually manual) operative work;
- Company internships: (“Stage en entreprise”) the HE student is placed in a real working situation; ideally, he or she will be in charge of a real working assignment;
- Research internships: (“Stage de recherche”) intended to develop innovation skills, they are recommended to the HE students who want to proceed to doctoral studies;
- Final engineering projects (“Stage de fin d’études”) frequently performed in a company or in a research laboratory, they often constitute an additional internship period.

In France, all these internships in companies or laboratories can be organised abroad, which adds an opportunity to “develop students’ ability to work in an international environment”. Graduate engineers who look for a R&D profile may choose long internships in laboratories, they must anyway spend at least 14 weeks as interns in a company. At variance with many “coop” programmes observed abroad, the French internships model for HE students do not prolong the studies but are included into them (to some extent at the expense of the summer holidays).

*Classical Integrated Programme Structure Including Internships for HEE Students*

In Europe, despite a deeply rooted liberal art style in some countries, “there is no consensus in structuring engineering education, but rather a constructive diversity in programme design” [Murphy et al. 2016]. Syllabus of learning outcomes [Crawley et al., 2007] can however be pivotal to align the programme structure and contents with the requirements of competency development. For such, as CDIO collaborators, both IMT Atlantique and CESI have followed such methods for continuous constructive alignments of their educational programmes.
At IMT Atlantique, economics, entrepreneurship, business, humanities and social sciences subjects are full constituents of engineering programmes, via sometimes classical lecture models but more and more since 2003 via transdisciplinary approaches based on problem- and project-based learning (PBL and PjBL). The classical integrated model at IMT Atlantique ensures that each HE student receives the intellectual guidance and experiences necessary to prepare them for vibrant engineering careers in a wide range of industrial, business and government settings. Since 2003, each HE student in the generalist programme of the Brest campus has to spend between 80 to 100 hours in team-based PjBL each of the five semesters (36 ECTS overall in the 3 years, inc. for the five semesters: 8 (S1), 6 (S2), 6 (S3), 10 (S4), and 6 (S5) credits), one day per week, under the regular supervision of methodological and domain tutors and with industrial partners [Rouvrais et al., 2006]. Aside, in its integrated curriculum, minors and majors include several mini-projects and PBL sessions. Each HE student carries out a minimum of 8 months of training in a company. A compulsory 6 months-minimum internship is in place at senior level. A compulsory 63-hours career preparation programme (21 hours per year) also supports the professional development [Rouvrais & Chelin 2010]. The periods of company “immersion” are important for the acquisition of skills, competency development and the affirmation of the professional and personal project. More than 40% of the generalist HE students also take a gap year in industry after their second year of study. An international stay of at least 9 weeks is also compulsory (e.g. via an academic semester or an internship abroad). It is even possible to carry out the last year of engineering studies alternating with a company for 12 months (under salaried status).

**Apprenticeship WBL model in French Engineers’ curricula**

In France, there is a continuous growth in the apprentices’ number in the engineering studies [CDEFI, 2015]. In 2014, about 130 HEIs offer 240 apprenticeship programmes. The apprentices now account for more than 14% of the total number of engineering students. While in 2014, 11% of the graduate engineers were apprentices, very soon this ratio will reach 15% (more than 5,000 graduates over a total of 35,000). In 1992, a French law extended the possibility to deliver higher education degrees through apprenticeships. The apprenticeship contract is a work & study training programme, where students (aged between 16 and 25) combine periods of work in a company and periods of study at the Training Centre to acquire skills and professional experience while preparing a diploma. The purpose of the apprenticeship is to enable students to undergo general, theoretical and practical training in order to obtain a vocational qualification attested by a diploma. Apprenticeship training has a positive effect on the occupational integration of young people: teaching them a job with practical experience makes them attractive in the labour market and offers them quick access to employment. In France, there were overall 365,000 apprenticeship students in 2015. Last but not least, the apprenticeship takes the form of a special contract between the student, the company and the school.

In the following years of the 1992 French law, CTI accredited a few institutions to award the “titre d’ingénieur diplômé” by apprenticeship to VET students. It remained for years a matter of relatively specialised institutions, like the CESI Graduate School of Engineering. In 1985, the situation changed because on one hand, the Government took incentive decisions for the companies which hired apprentices. On the other hand, the French engineering schools were searching ways of increasing and diversifying their student’s recruitment to VET students. CTI accredited more and more “classical” engineering schools to develop curricula by apprenticeship (as at IMT Atlantique, Telecom Bretagne School of Engineering, since 2002), the new paradigm of learning outcomes (LO) allowing to prepare the same diploma by
different tracks (i.e. the same set of LO but with different programme contents) [CTI, 2011]. Per the French law, apprentices are not students, they are VET professionals, they have a work contract and get a salary (from 40% to 90% of the minimum legal salary). A formal contract (3 or 2 years) between the company and the HEI states the educational objectives, the respective responsibilities of the company and the school, the schedule of the work and school experiences, etc.). Usually, the VET apprentices spend about 40% of their working time in the company, the rest at school; with an equivalent share of ECTS credits.

A follow-up of VET apprentice graduates shows that their professional trajectory is as good as the “classical” HE graduates; they are not confined to pure production jobs, although they are less employed in R&D departments of large companies. A still better indicator is the increasing number of applicants with top records who choose the apprenticeship track.

**Apprenticeship Programme Structure for VETE Students**

At IMT Atlantique, since its creation in 2002 on the Brest campus, the apprenticeship programme relies, for the VETE students, on a progressive alternation between the institution and the company, including, for apprentices enrolled in 2016, an international stay of at least 9 weeks. The WBL model is organised as follows [Rouvrais et al., 2007], where AP being the academic periods (114 ECTS overall) and CP being the company periods (66 ECTS overall):

- year 1: 4 weeks AP1, 6 weeks CP1 (4 ECTS), 5 weeks AP2, 12 weeks CP2 (8 ECTS), 13 weeks AP3, and 12 weeks CP3 (6 ECTS);
- year 2: 11 weeks AP4, 11 weeks CP4 (8 ECTS), 13 weeks AP5, and 11 weeks CP5 (8 ECTS);
- year 3: 15 weeks AP6, 9 weeks CP6 (8 ECTS), 6 weeks AP7, 29 weeks final CP7 (24 ECTS).

Engineering training at CESI is a 3-year curriculum that students can embrace after a Diploma of Higher Education. Throughout these three years, in-company times are punctuated by periods at school from 2 to 10 weeks for a total of 54 weeks over the 3 years. Besides, 5 weeks are dedicated to laboratory research and 12 weeks to a mission abroad. Taking advantage of its syllabus review, the engineering school has developed a pedagogical method that combines PjBL and PBL. This method is based on iterative loops to get closer to the operations of in-company engineers. Internally called "A2P2", for Active Apprenticeship by Projects and Problems, it was implemented in 2015-2016. The project topic is close to a real problem that could be experienced in companies, with multidisciplinary content. To solve the various problems that appear, students must acquire disciplinary knowledge, which is then applied to the project. It is an ideal opportunity to integrate knowledge, methods and tools from different disciplines of the curriculum and to make connections between subjects that are often learned separately. This project is divided into three main phases. First of all, (i) a launching phase, during which the students must define their roles (facilitator, scribe, secretary, manager), (ii) a second phase where the working group is to read the project statement, discuss the need, and rephrase it. The group also receives the project synoptic and must identify all the deliverables requested at the end of the project. Then, (iii) during the realisation phase, students carry out a succession of PDCA iterations (ie. Plan, Do, Check, Act), which gradually lead to targeted learning outcomes and final products. This phase can last from 1 to 5 weeks.
RETURN ON EXPERIENCE ON WBL IN FRENCH ENGINEERING SCHOOLS

Recent discussions (Vienna 2016) on the European Qualifications Frameworks showed that for most professional engineer representatives, academic training should not be compensable by professional experience, underlining the idea that learning on the job-site has not the same value as the academic one. In the French engineering community, the opinion is different: the real professional situations encountered in internship and apprenticeship WBL models reinforce the proactive role of the learner in acquiring the knowledge necessary for the execution of his/her mission, thus promoting the autonomy development, the ability to adapt to some unexpected situations, and to evolve towards new technologies and a priori unknown situations (e.g. career kaleidoscope, nomadic careers). By experience at CESI and IMT Atlantique, WBL HEE and VETE students are more in line with the needs of recruiters in terms of attributes and skills once graduated, have a foot in the door, and are more operational once hired. This section presents some French modalities which may limit the biases of WBL and foster academic formal recognition of work-based learning more formally in an integrated curriculum.

The learner/supervisor/tutor trio

Specific pedagogical methods are required for WBL models. Logics of knowledge transmission in the academic side and logics of operation, performance, efficiency, and productivity in the company side must coexist and enrich each other, with synergies. It is difficult to define uniformly the content of each of the corporate missions in WBL due to the diversity of the hosting companies (e.g. large industry groups, operators, equipment manufacturers, IT services companies, banks, or insurance companies), the diversity of occupations or missions and the diversity of organisations encountered. However, to promote the learning effectiveness and alignments of the proposed missions with the activities during school training, a substantial effort is to be made in order to increase the formalisation of the core skills and competencies. In France, a HEE or VETE WBL student in engineering is continuously supervised by a company senior engineer in the related field of training and by a pedagogical tutor for the academic side. The academic tutor visits the company several times to meet the learner and his/her supervisor, participates in monitoring the learner development, facilitates the learning outcome framing and fosters to put into perspective the training objectives and experiences. This learner/supervisor/tutor trio [Rouvrais, 2007] is an essential triangular consortium in which the interactions are regular, improve follow-up, and promote reflexivity. As an example, the trio sets the missions and learning objectives before each WBL period, and communicates them to the academic services for validation (e.g. alignment with the learning outcomes and proficiency levels required for a period). The curriculum logistic is thus very demanding, not only to organize the tutoring.

Skills and competences developed during WBL company placement

Although universities and engineering schools include in their pedagogical styles learning situations close to the reality of the engineering practice, many professional skills remain difficult to instantiate realistically in pure academic environments. Most often, the situations are simulated, thus with several biases, where students have their own perception of the corporate world (or even sometimes academics) and may develop misconceptions and stereotypes, having difficulty to accept the theoretical learning objectives fixed by the teaching staff. Impacts of WBL and work placements on the development of students’ skills have been extensively studied in the literature, even in engineering education [Saunders,
1995; Ahmed, 2009; Onof, 2010]. As strong motivational factors, WBL in companies for engineers are experiences to be exploited regularly in the formal curriculum, in line with the autonomy required for future operational engineers [Rouvrais, 2007]. Engineering programmes are more and more oriented towards competences, with a view to training in relation to real professional situations. Apprenticeship WBL models, with their school/company transitions, are modalities that respond particularly well to the skills and competences orientation, via contextual working occupations. WBL Logics of knowledge transmission in the academic corner and logics of operation, performance, efficiency, and productivity in the company corner coexist and enrich each other. WBL classically permits students to mobilise their formal knowledge and skills in real contexts, in non-simulated environments, and thus develop real professional competences. By developing a corporate culture and sense of responsibility, WBL also request interpersonal skills, team integration and operation skills, professional behaviour, and corporate cultures, strategies and goals. Not least, WBL models permit HE or VET students to regularly echo lived experiences in their formal curricula and thus develop real professional competences. By developing a corporate culture and sense of responsibility, WBL also request interpersonal skills, team integration and operation skills, professional behaviour, and corporate cultures, strategies and goals. Not least, WBL models permit HE or VET students to regularly echo lived experiences in their formal curricula and thus develop real professional competences. By developing a corporate culture and sense of responsibility, WBL also request interpersonal skills, team integration and operation skills, professional behaviour, and corporate cultures, strategies and goals.

CTI urges to make apprenticeship a success and not a second-hand path: precise definition of expected learning outcomes, role and training of the apprentice’s tutors (in the company and at school), innovative pedagogy adapted to new profiles of students, etc. For accredited apprenticeship programmes, quality assurance and enhancement procedures are in place which ensure WBL integration and control on the pedagogical dimensions [Rouvrais et al., 2007]. At IMT Atlantique, the learning outcomes referential is formalised in the apprenticeship programme for VET students, in line with targeted professional branches requirements. The seven company periods (CPI) permit to cover all these outcomes, including proficiency levels on a continuous basis. The companies do not fix alone the mission given to an apprentice for a period. It is managed by the academic institution (i.e. a specific service including programme leaders and career orientation managers) and the trio apprentice/supervisor/tutor. For each period, a constructive negotiation is instituted ahead of “day one”, to be signed by each party. This negotiation permits to legitimate the learning and competency development objectives of the academic side to the company specific environment, in order to strongly limit the “most of student working” effect for the only benefit of the company. In this negotiation is recalled what has been acquired in terms of knowledge and skills by the VET student in the previous academic periods. An apprentice student is formatively assessed several times throughout the periods, including self-perception on proficiency development.

**WBL student exigencies in the formal curricula**

A classical main pitfall of apprenticeship is to consider this WBL model as just a way for the VETE students to get a salary and as a less quality-demanding curriculum. In the French VET engineering education, the students’ workloads are very heavy, their vacations are much shorter than those of “classical” HE students, i.e. they are employees. Both at CESI and IMT Atlantique, apprenticeship accredited programmes for VETE students were set up on demand of companies that have expressed the need to hire operational engineers, endowed with technical and managerial skills, a good culture, and already possessing a potential for autonomy, adaptation and evolution. In the general context of apprenticeship, apprentices may experience difficulties to return to school, because they notice a gap between the way they function at work, and the posture expected in transmissive pedagogy.
Thanks to the CESI and IMT Atlantique long-term experience of WBL, students back in the academic environment after a company working period prove to be more demanding with regard to the courses they attend, what points their ability to take a critical step back from the learning objectives and contents of the various courses. Under the influence of their experiences in companies, their analyses involve criteria of performance, potential re-use and transfer of knowledge. They thus become more active actors of their own training. But they can also become censors: a theoretical course targeting high-level cognitive skills may be under pressure due to their non-direct applicability. In line with the Kolb inventory of learning styles [Kolb, 1976], concrete experience may refrain abstract conceptualisation for pragmatists and activists, as often experienced with VET students. On the academic side, such critical student feedback is exploitable by the teacher via an exchange and open discussion with the peer learners, whose critical opinions may be reframed to the extent that perception of the performance of a teaching activity is not always temporally localised with the skill and competence development.

**INSIGHTS FOR AN EDUCATIONAL FRAMEWORK**

It was shown by Edvardsson Stiwne and Jungert (2010) that many engineering students argued that generic skills and cultural values are best learned in extracurricular activities and in work contexts, and that doing a thesis project in a firm was the best learning experience. In order to include an early exposure of engineering students to professional practice, integrated curricula in line with latest programme outcomes (i.e. ABET graduate attributes at Master level or ENAEE areas of programmes outcomes [EUR-ACE, 2015]) are in place in several engineering HEI. Among them, industry partnership is to be considered as rational for most of the reference models and maturity levels, even more with the growing importance of international internships. Nevertheless, a profound reengineering of engineering education [Borri and Maffioli, 2007] may not be so necessary, knowing that some frameworks clarify many good practices to meet such requirements. For engineering programmes, as promoted by the CDIO framework, the association of several stakeholders in the quality enhancement processes is recognised. The existing twelve CDIO reference models can be put to the test in order to draft opportunities of its reference models adaptation for professionalisation purposes and, ultimately, improvement of the quality of engineering higher education from various stakeholders’ viewpoints.

Taking inspiration from the twenty guiding principles for apprenticeships and WBL [European Commission, 2016] proposed by the Education & Training 2020 working group in EU and the accreditation criteria and guidelines of the French CTI [CTI, 2016], to sustain industry-University partnerships (e.g. as argued in [Morell, 2014]), some extensions may be suggested to the twelve CDIO reference models. Due to the numerous concerns of WBL and their vast echoes in an educational framework for engineering education, creating a specific reference model may perhaps be considered in order to move forward institutional and policy implications, as e.g. a new thirteen “Industry Partnership” dedicated CDIO reference model, aligned and consistent with the twelve existing ones. It could be defined as this:

(13) **Industry Partnership**: partnerships with various types of companies (regionally, nationally and internationally) are in place in the institution and within the formal integrated curriculum. Adequate models of WBL support student competency development of product, process, system building, knowledge, personal and interpersonal skills, so as of company social contexts and related professional responsibilities.
a. **Rationale:** the curriculum and learning outcomes can only be designed if there are corresponding authentic pedagogical approaches, in and out of the formal curriculum. Students recognise professional engineers as role models, instructing them in disciplinary knowledge, personal and interpersonal skills, and product, process, and system building skills, in line with competency requirements of professional bodies. With WBL experiences in place for their students, faculties can also be more effective in contextualising their courses and better prepare their students to meet the demands of the engineering profession and to become lifelong learners.

b. **Rubric (maturity scale):**

0. There is no evidence of industry partnership nor of WBL in the programme;
1. Industry partnerships and WBL model plans have been benchmarked with respect to the integrated curriculum plan;
2. Industry partnerships and WBL plans with learning outcomes and real professional activities that integrate personal, interpersonal, conceiving, designing, implementing, and operating skills and competencies with disciplinary knowledge have been approved, in the enterprise and social contexts;
3. Student WBL experiences and formal industry implications are being implemented across the curriculum according to the integrated curriculum plan;
4. There is evidence of the impact of the implementation of WBL experiences and formal industry implications according to the integrated curriculum plan;
5. Formal industry implications and student WBL experiences are regularly monitored, evaluated, and revised regarding their curriculum integration and the impact of these professional experiences.

To sharpen the conceptualisation of WBL curriculum integration, 30 years of good practices recorded from the French experience may be generalised and transferred in such a new reference model to capitalise and share experience at European and international levels.

**CONCLUSIONS**

Internship is inscribed in the genes of the French engineering education [Maury, 2010] and [CTI, 2011]. For French HEI, there are now less and less CTI recommendations concerning the lack of compliance with the related criteria. A recent survey showed that internships represent 23.5% of the training duration and that 18% of graduates underwent an internship abroad (only the engineer cycle is considered here, i.e. the last 6 semesters for Master level graduation). The main pros of integrated internships are (i) opening of the engineering studies to students with different skills, for whom the inductive pedagogy (from experience to theory) is more efficient than the classical deductive one, (ii) better understanding of academia and employers of their mutual constraints and objectives, (iii) enhancement of HEI to adapt their curricula to the employers and society needs. The main cons of integrated internships are (i) the risk that employers consider apprentices as mere employees and let the company constraints overrun the training project, (ii) companies must be aware and academia must watch carefully that the objective is not the training of ready-to-use engineers but the training of young people for several tens of years of professional career in an evolving environment. This analysis may provide some inputs to international engineering education collaborators investigating to include WBL as integrated activities in their programmes to better bridge some gaps with industry requirements and integrated programme skills.
As pointed in [Rouvrais, 2012], adults, as students, have an active role in their own learning and training. Non-formal and informal education, e.g. out of the formal academic environment, is the cornerstone for lifelong learning and career development. But related knowledge and skills are sometimes hardly recognised in the formal education arena. Candidates for a diploma or certification derived from professional experience or continuous vocational, have to confront more or less to referenced educational syllabus of learning outcomes. In French engineering education, according to the CTI standards, about 30% of the ECTS credits must be assessed in the workplace by a joint team of supervisors (inc. academic professors and tutors, and professional mentors). In the WBL internship and apprenticeship models presented in this paper, CESI and IMT Atlantique provide guarantees on control and monitoring of skill development. They control learning outcomes during and at the end of the working periods thanks to the trio learner/supervisor/tutor follow-up. Regular formative and summative assessments, self-assessments, restitutions to the learner by a competency and career expert, are in place. Capitalisation on peer experiences via collaborative student workshops, specific training sessions for supervisors in the academic environment, also exist. For example, on-site visit certificates of the academic tutor in the apprentice company, formally required by the professional branches supporting apprenticeship models in France, are to be signed at least once a year with the parties and HR managers.

Although the practice of internships has overrun all French degrees, companies praise the engineer internships, because they offer them a return. Additionally, the company might be able to promote itself among students, get a better knowledge of the profile of young professionals that will soon come to the job market, incidentally appreciate the quality of an intern and offer him/her a job when he/she ends his/her studies. The risk from both the company and HEI sides is that internship would be considered just as an accumulation of working periods in companies, where the students are not on campus. As a guardrail, CTI requires precise coordination between the teaching in and out the campus, with detailed follow-up processes. Academia sometimes consider that WBL models have not the same standing as general education or academic formal education, relying programmes are often regarded as second-rate education. Nevertheless, as in France for engineering education, WBL models are in place in several countries and since a long period of time. Many good practices are transferable, as already clarified in the literature (e.g. [ASTE, 2009]) or in European recommendations [European Commission, 2016]. In this paper, the authors have thus suggested the establishment of a 13th CDIO Standard, concerning Industry Partnership.

Policy implications of WBL are to be considered. A statistical study [Kailis and Spyridon Pilos, 2005] showed in 2005 that about half of the 25-64 years old in the European Union have an active role in their own learning. In several EU member states, knowledge and skills acquired and developed thanks to informal and non-formal learning can already be certified. As such, some higher educational institutions can award their diploma on the basis of a recognition of prior learning and work experience (RPL), based on professional and life experience [European Commission, 2012]. In France, since its formal inscription in the Law in 2007, it is an obligation for HEI, even in engineering. French RPL allows professionals (e.g., technicians with several years of experience in engineering), whose profile, i.e. the knowledge and skills acquired, matches the graduate outcomes formally defined by the degree programme and national qualification framework (called RNCP in France), to obtain the engineering degree from an authorised and accredited School of engineering [Rouvrais, 2012]. There often remains a distance between the competencies repositories of the professional world and those of the formal curricula, more knowledge- and skill-oriented. Indeed, the position of France in RPL of engineering skills remains original in the European
lack of experience. In a 2016 academic leaders meeting on ECTS, several participants remain reluctant to the approach.

**Insights**

In the specific context of this paper analysis, opportunities for further innovations (Innovation of Practice, e.g. IP) in engineering education approaches can be suggested:

- **(IP1)** creating a full reference model of WBL to be integrated in educational frameworks for engineers, supported by constructive alignment principles and good practices per maturity levels for institutional application;
- **(IP2)** defining a unified framework bridging several pedagogical modalities for similar degrees. In the EUR-ACE language, learning outcomes permit to realign profiles. In such a Learning Outcomes approach, programmes are defined by their expected outcomes not by the way to achieve them [EUR-ACE 2015], which allows to deliver the same degree to students following different tracks (academic curricula, apprenticeships, continuing education, validation of professional experience). In France, the legal regulations, implemented by the CTI requirements, have given HEI a strong experience to bridge the various training modes in the engineering graduation.
- **(IP3)** transposing the French WBL models to other countries, e.g. by including legal context and framework, so as fostering industrial lobbying and collaborations. It should be noted that several requirements must be fulfilled to develop WBL: a large industrial basis offering the whole spectrum of engineering activities; a legal frame for the students while they are on the worksite including salaries and social security issues, employers ready to dedicate human resources for the tutoring of HE interns or VET apprentices, academia ready to involve all stakeholders -particularly employers- in the training design and assessment, teachers willing to contribute to the on-site tutoring of the students. The idea that there may be an external industrial council that can give advice on educational programmes, pedagogical styles and contents can boil in some HEI environments.

Thanks to this paper’s elements of analysis, new potential research questions (RQ) could then be inferred:

- **(RQ1)** What are the career decision making factors and processes of engineering students and how do they impact them? A recent qualitative study in the IMT Atlantique context has analysed first job preferences and expectations of the school’s HE students before their first internship [Gerwel, Chelin, and Rouvrais, 2017]. It showed some motivational factors echoed in students’ course choices, students’ WBL situation choices, and first job choices. These are to be analysed further, e.g. qualitatively and quantitatively, and maybe to be correlated to clarify student decision-making processes for WBL and career choices;
- **(RQ2)** How to measure the true quality and benefits of WBL at a systemic level for objective quality assurance? Some academics like to say that internships (“stages” in French) are just a way for companies to rip young students off and make the most of student labour with low salary and taxes. It might be true when no control loop aligned with learning outcomes is fixed by institutions in WBL models. Specific quality assurance procedures and objective analysis via longitudinal methods may be more deeply investigated to corroborate or not;
- **(RQ3)** What are the correlations between learning styles and pedagogical models in engineering education, how do they echo in learning cycles? In WBL, logics of knowledge transmission in the academic side and logics of performance, efficiency, and
productivity in the company side must coexist. It was shown in this paper that students may become censors in the academic environment, especially when high-level cognitive skills are faced by pragmatist and activist students in the Kolb sense [Kolb, 1976]. Learning loops including WBL, PBL, PjBL and more classical courses may be analysed in light e.g. Kolb theory (even if contested) of concrete experience, reflective observation, abstract conceptualisation, and active experimentation learning styles (and maybe also the Learning Styles of [Felder and Silverman, 1988]).
REFERENCES


**BIOGRAPHICAL INFORMATION**

**Prof. Bernard Remaud** is professor emeritus at the University of Nantes. From 1995, his main activities were oriented towards the management of higher education institutions, the quality assurance and the assessment of engineering education. He developed the Polytech network which includes 13 French engineering colleges. In 2004, he was appointed at the CTI (French Committee for Engineering Programmes Accreditation), and served as an executive director until 2012. In 2014, he became president of ENAEE.

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