EXPERIENCES OF EDUCATIONAL REFORM – IMPLEMENTATION OF CDIO AT INDUSTRIAL DESIGN ENGINEERING

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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, 2016). 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 vas 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 cafeteria 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)

gure 1. IDE design studio in 'presentation' mode.

Figure 2. IDE design studio being used for practice-based projects

Figure 3. The 'garage': a large storage area that stores a full-scale driving simulator along with lots of other materials.

gure 4. IDE student working with a clay prototype one of the workshops.

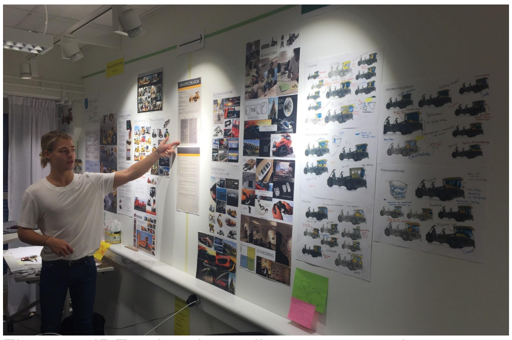

Figure 5. IDE using the wall to present project progress in one of the project areas.

Figure 6. Mockup of a truck cabin in the IDE design studio.

gure 7. Informal learning environments at IDE: afeteria and study-spaces.

Figure 8. One of the workshops in use- illustrating practical design-implement experiences

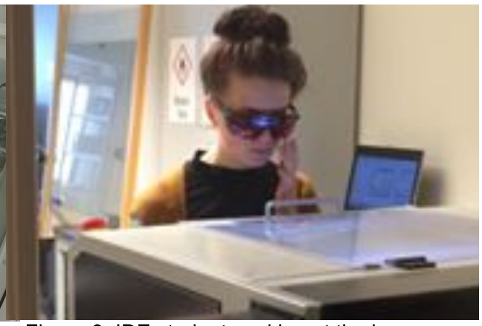

Figure 9. IDE student working at the laser cutter in the prototype lab.

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 i 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 & Törlind, 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

Standard	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
2015	1	2	2	4	4	3	4	3	3	1	3	2
2016	2	4	3	4	4	4	4	3	3	3	3	2

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.

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