A 10-year teachers' journey toward CDIO: lessons learned for dealing with students, companies, and yourself

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ABSTRACT

The paper summarizes the experiences of working for a decade to promote the transition of courses toward the CDIO framework. It presents a list of lessons learned when applying the CDIO principles in master-level classes in the field of Mechanical Engineering. The paper aims to formalize operational guidelines, serving as a platform for further discussion and as a set of practical recommendations for teachers and educators initially redesigning their courses toward a more CDIO-oriented structure. The paper initially presents the rationale for moving toward CDIO and describes where and how data were collected. Further, it lists several lessons learned for teachers on (1) how to support students in maximizing their learning opportunities in a CDIO context, (2) how to manage the relationship and engagement with company partners, dealing with expectations, trust, flexibility, and visibility.

NYCKELORD

CDIO implementation, Mechanical Engineering, Lessons Learned, Guidelines.

INTRODUCTION

In education, experiential learning has been discussed for several decades. In 1975, David Kolb and Roger Fry argued that effective learning entails possessing four different abilities: ' concrete experience', 'reflective observation', 'abstract conceptualization' and 'active experimentation' (Kolb and Fry 1975).). This four-stage holistic model is further known as the Experiential Learning Cycle and highlights the role experience has in the learning process for the individual. Experiential learning is a crucial characterizing component of both the CDIO Standard 8 (Active Learning) and 10 (Enhancement of Faculty Teaching Competence) (Malmqvist et al. 2020).). Active learning methods engage students in thinking and problem-solving activities – including discussions, demonstrations, debates, concept questions, and student feedback about their learning. Experiential learning takes a step further to simulate professional engineering practices. This is obtained, for instance, through the creation of ad-hoc design-implement projects, simulations, and case studies. The primary rationale for active learning to become 'experiential' in the CDIO framework is to have students taking action, playing the role of professional engineers, reflecting on their outcomes, and iterating this cycle.

The movement toward a CDIO approach changes how students approach university education and engage in course activities as primary actors, learning by doing and developing multidisciplinary skills beyond the traditional engineering disciplines. As educators enabling the transition toward CDIO, teachers should also embrace such transformation and be able to develop different personal skills dealing with different dynamics emerging in university courses.

The paper presents a list of lessons learned, summarizing the experiences of the authors working for a decade to promote the transition of several courses toward CDIO. The purpose of the paper is to formalize operational guidelines, serving both as a platform for further discussion and as a set of practical recommendations for teachers and educators starting the journey toward CDIO-oriented courses. The paper initially presents the rationale for moving toward CDIO, later describing the research approach, methods, and context. Finally, the paper lists twelve lessons learned for teachers on (1) how to support students in maximizing their learning opportunities in a CDIO context, (2) how to manage the relationship and engagement with company partners, dealing with expectations, trust, flexibility, and visibility.

EFFECTIVE LEARNING

The four-stage holistic model known as the Experiential Learning Cycle (ELC) (Kolb, 2014) highlights the role experience has in the learning process for the individual. While the learning cycle can begin at any of the four points in a continuous spiral fashion, it often starts with a person carrying out a particular action and then seeing the effect of the action in this situation. Active involvement is critical in these concrete experiences: to learn effectively, one must actually do something and not merely watch or read about it. The second stage in the cycle is that of reflective observation. This means stepping back from the task, taking a time-out from 'doing', and reviewing what has been done and experienced. The Abstract Conceptualization step involves interpreting the events and understanding their relationships to understand what happened and why. At this stage, the learner may draw upon theory from textbooks to compare what they have done, or they may refer to previous observations or models they are familiar with to reflect upon what they already know. The final stage of the ELC is understanding translating into predictions: the learner plans to put what he/she has learned into practice, deciding what actions should be taken to refine or revise how a task is to be handled.

While the ELC is praised for challenging those models of learning that seek to reduce the potential to one dimension, such as intelligence, it has been recently criticized for different reasons. While it pays insufficient attention to the process of reflection, the idea of stages or steps needs to sit better with the reality of thinking, and the relationship of learning processes to knowledge is problematic (Jarvis 1995). These issues have paved the way for developing more comprehensive models to explain the nature of learning. Jarvis (1995) describes several responses to potential learning situations: non-learning, non-reflective learning, and reflective learning (including experiential learning as a sub- route). In Jarvis' view, even though it makes sense to say that everybody learns from their experiences, the problem becomes how to create experiential learning 'count' in the specific context of the educational system, institution, and discipline at hand. Furthermore, for learning to be valid, most people need to place it in a context that is relevant to them. If learning is not helpful, it will likely be forgotten quickly.

Experiential Learning and CDIO

Being able to foster experiential learning is critical in the frame of CDIO. As Edström K. and Kolmos, A (2014) pointed out, Educational development in the CDIO Initiative focuses strongly on developing student's professional skills, understanding of engineering work processes, and ability to work and collaborate in engineering organizations. To accommodate the nature of these learning outcomes, it is necessary in most programs to increase the share of so-called Design- Implement Experiences within the programmes and through the application of many other active and experiential learning methods in the integrated curriculum. At the same time, the CDIO Syllabus 2.0 (Crawley et al., 2007) introduces the ability to act in an entrepreneurial way to be critical for the engineers of tomorrow. This is because, in modern society, engineers are increasingly expected to move to leadership positions and take on additional roles as entrepreneurs. The engineer needs to understand the trade-offs between product novelty vs time to market, product margins, and hurdle rates needed to justify company investment, together with other business considerations that influence design and implementation strategies. Engineering education should prepare students for becoming entrepreneurial. Preparation for entrepreneurship involves unique competencies, and experiential learning is critical to fostering an entrepreneurial mindset in engineering education (Bosman and Fernhaber 2018).

RESEARCH APPROACH AND RESEARCH CONTEXT

The research data were collected through a qualitative approach from selected courses in the 'Innovative and Sustainable Product Development' specialization of the Mechanical Engineering MSc programme at BTH. The courses go under the names of 'Value Innovation', 'Systems Engineering', 'Knowledge Enabled Engineering', and 'Extreme Product Service Systems Innovation'. Following CDIO recommendations, the courses were designed with an overreaching project work in collaboration with selected company partners, which kicks off just after the course introduction and stretches along one or two study periods (i.e. 8 or 16 weeks). Each project was conducted by small teams (4 to 6 participants). Data were collected between 2013 and 2023 during several iterations of the courses and probed through retrospective analysis and self-reflection reports, where students were asked to explicitly state the most significant lessons learned and experiences during the course project. Standard course survey issues at the end of the courses were used as additional data collection channels for gathering student feedback about industry-company collaboration.

LESSONS LEARNED DURING THE CDIO TRANSITION

Supporting students in maximizing learning opportunities

LL1: Support "incremental learning" through active learning

Active learning in higher education fundamentally means involving students "in doing things and thinking about the things they are doing." (Bonwell and Eison 1991). Active learning in the classroom was first introduced by promoting group tasks into the traditional lecture, encouraging students to manipulate, apply, and reflect on the practical use of the presented methods and tools. Group exercises – where students work together in different group constellations to tackle problem-solving tasks – have been extensively used in the courses to activate students' learning. Each task lasted between 10 to 15 minutes and was conceived to mix students with different backgrounds and skills (when possible) and engage them in multidisciplinary work. These exercises mimic the group and individual assignments and represent a 'testbed' for students to familiarize themselves with methods and tools. During the years, we observed that students appreciate the opportunity to go hands-on with the toolbox and to learn 'by doing' in a controlled environment before replicating the task in 'real-life' projects. One successful way to activate students in the classroom is to manipulate physical products. Vacuum cleaners, barbeques, coffee machines, backpacks, and more are some of the products being used in these sessions. These activities form the basis of the initial 'formative feedback' loop. Since the goal is to ultimately have the students reach the learning outcome by the end of the course, the teacher should expect students to make mistakes at the beginning and refrain from grading them on the "hands-on" activities of the course. Early course assignments proved suitable for testing students' engagement but encountered the risk of being perceived as threatening by those who wanted to achieve a high grade. This could result in students not being eager to propose radical innovation because they fear making mistakes that could impact their final course grades. This issue was addressed by evaluating such sessions based on the student's capabilities to reflect and elaborate on the process and on the results rather than on the final output. In a nutshell, the organization of design sessions/role plays/experiments at the beginning of the course helped students grow their confidence in how to apply theory and methods to complex industrial problems.

LL2: Align the learning activities with the project activities

The project activities are the core of the learning process in a CDIO-based course. A challenge that emerged during the courses was to provide the students with the necessary background to start working on the project assignment as soon as possible. In a CDIO setting, the risk is to ask students to face the industrial problem by applying specific methods and tools while those have not been introduced yet in the course lectures. In such a setting, the need to align classroom learning activities immediately before or in parallel with the project activities emerged clearly. Therefore, the lectures were organized in a way that followed the challenges that the students might encounter in the course of the project. This can be done, for instance, by concentrating on key lectures at the beginning of the course and fewer lectures toward the end.

LL3: Show and spread engagement

The risk of students collaborating with companies is for the teacher to "lose contact" with what is happening in the project and what kind of feedback and directions the students receive from the industrial contact. As an educator, there is a need to not merely act as a process controller but instead be engaged in the project. The students' engagement is nurtured by the teacher's active engagement and feedback on the problem-solving activities and the request of updates in a formal and informal environment.

LL4: Challenge the students, but understand the group composition

The students are aware that CDIO-inspired courses are not the traditional ones they have encountered at the beginning of their studies, creating new and different expectations. Such expectations can vary a lot from one group of students to another. Similarly, the performances of the groups can be very different. There will be highly- performing groups and poorly-performing groups. The teacher is here asked to understand the team dynamics and the group composition to challenge the highly performing teams and support those who are delivering lower performances. There is a need to build awareness of the typical team dynamics processes and support teams to go over critical moments (see literature in team dynamics such as Tuckman and Jensen, 1977). Additionally, project expectations shall not be based on low-performing groups, since this will demotivate and discourage the effort of the highly-performing ones.

LL5: Set reachable goals, but expect more

Despite the requests and requirements from the partner companies, the course is, in essence, a learning activity. The students need to have a clear idea from the beginning of the course about the goals to be achieved (and about what will determine the final grade). Such goals shall be achievable irrespectively from the company partners' engagement level.

LL6: Overcome the students' 3-weeks crisis

Students' excitement about a project usually fluctuates after a couple of weeks. This phase is referred to in project management literature as the "storming" phase in team dynamics (Tuckman and Jensen, 1977). In this stage, students commonly start to worry about the project being too complex and the information being too limited, concurrently questioning their skills and capabilities to provide relevant solutions for the company partner. Project management literature indicates the failure to go over the storming phase as one of the main reasons many groups fail to deliver their full potential. When such dynamics emerge, planning active learning activities provided practical support to let students practice their knowledge and skills during this delicate phase of the project.

LL7: Make constructive critique on both learning outcomes and industrial results

Evaluating and grading a student project from a CDIO perspective is not trivial. The course's intended learning outcomes often do not coincide with the expected results from the company partners. What emerged as clear during the courses is that the students expect the teacher to provide feedback and evaluation from both perspectives. The students expect companies' feedback to be critiqued, so they want you as a teacher to have constructive critique on their industry-related results as well as on the fulfillment of the intended learning outcomes.

Managing relationships and agreements with partner companies

LL8: Select local companies

Selecting local companies geographically close to the students' primary study location, was particularly beneficial for students. In this way, students could more easily and frequently perform observations and interviews in a real-world setting, facilitating the analysis of expectations and needs for new solutions, hence contributing to the authenticity of the projects. Physical proximity has also been shown to facilitate the social construction of knowledge. Regular interaction with stakeholders from industry and society has helped students gather focused feedback on their achievements and deepen their reflections on different topics. At the same time, a purposeful choice was made to move from large-scale systems to simpler devices/services progressively. This allowed students to be exposed to aspects of actual operation, reinforcing the later stages of CDIO. For students, this also meant increased opportunities to be seen and make a difference, the latter having a beneficial effect on social motivation, a critical aspect of learning (Biggs and Tang 2011, p.35).

LL8: Plan ahead of time but be ready for quick changes

Companies and universities work with different time paces and different priorities. Companies are often slow in answering and need internal time to assign responsibilities and clear access to information. In some cases, companies might not come to a final decision on time, so be prepared for a plan B. If you are recurrently working with the same company over the years, keep notes of potential projects that emerged during the discussions and be prepared to make students working on a very similar topic to invite the company later to join the course while is already running.

LL9: Clarify the expectations

Start the preparation of the course well in advance. Contact the partner company approximately 4 to 6 months before the course starts. Ask the partner company to formulate project proposals and submit them to you two to four months before the class begins. At least one month before the course kicks off, ensure a responsible contact person at the company is identified and possible dates for company visits and guest lectures are set. Before the course starts, define a time for the internal company presentation if you plan to have one. Yet, always remember that universities and external partners work at different paces and with other priorities. Companies might have largely different priorities than you t; hence, be prepared to accommodate delays in the work. For this reason, keep an eye open for those challenges that feel more urgent, which might lead your contact points to be faster in answering and assigning internal resources and responsibilities to have better and more readily accessible information. In some cases, they might not come to a final decision on time, so in the planning process, be constantly focused on preparing a Plan B, and possibly even a Plan C. If you are recurrently working with the same company over the years, keep notes of potential projects that emerged during the discussions and be prepared to make students working on a very similar topic to invite the company later to join the course while is already running.

LL10: Build trust and act as a gatekeeper

Make it clear to the company what the project timeframe is (i.e. how many weeks and what percentage of time the students are spending on it). Also, remind them that, as a student's work, the project might go wrong and fail. Clarify to the company the difference between a student project and a research project and that you, as a teacher, cannot guide the results of the student groups. This is particularly relevant if the company partner is used to working in research collaboration with the teacher, causing the risk of considering the teacher as responsible for the students' project results. After the course, self-reflect on what was not working in the course in terms of industrial collaboration.

Plan for a change of company partner if needed. This might require more time and commitment from you, but it might be beneficial for the course.

LL11: Make students' work visible: make the intangibles tangible

Set up the course activities and communicate the results so that company employees realize that a university course collaboration is going on. This refers to people other than the direct company contact, i.e., his/her colleagues or other managers. This can spark future collaboration and new ideas. In other words, make the intangible collaboration visible and "tangible" for the partner companies, for instance, by organizing the course's final presentation at the company facilities, or by delivering posters or physical prototypes, summarizing the final project results to the company facility. Besides providing extra motivation to the students, this allows more people from the company to take part in the final results with relatively low time effort, and it conveys engagement toward the company helping to build a long-term relationship.

LL12: Plan well ahead of time

Start the preparation of the course well in advance. Contact the partner company approximately 4 to 6 months before the course starts. Ask the partner company to formulate project proposals and submit them to you two to four months before the class starts. At least one month before the course starts, ensure a responsible contact person at the company is identified, and eventual dates for company visits and guest lectures are set. Before the course starts define a time for the internal company presentation, if you plan to have one.

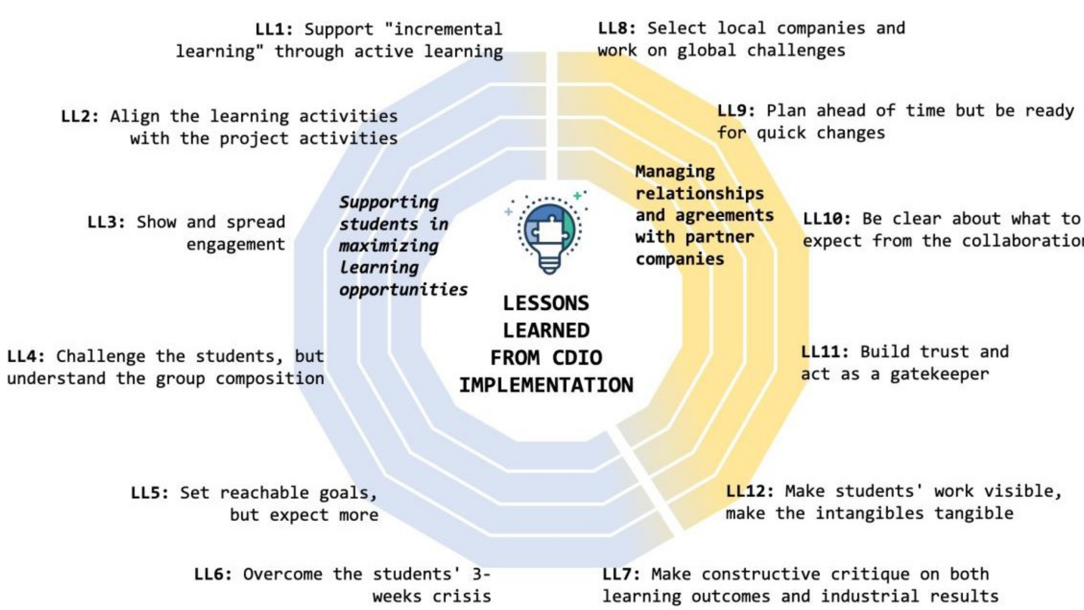

Figure 1. Summary of the lessons learned on the transition toward CDIO implementation.

CONCLUDING REMARKS

The task of engineering educators is teaching students who are "ready to engineer, that is, broadly prepared with both pre-professional engineering skills and deep knowledge of the technical fundamentals" (Crawley et al., 2007, p.11). Several examples of CDIO implementations are described in literature from multiple case studies and standpoints. This paper does not claim to expand the body of theoretical knowledge about CDIO, rather, it summarizes the experiences of the authors who have worked for a decade to promote the transition of several courses toward CDIO. The lessons learned presented shall be seen as the operationalization of the authors' theoretical knowledge supported by the empirical findings collected during the years, thanks to the interaction with students and companies. The collected data and experience are qualitative and collected in a context that has changed over the years, in courses that have iteratively been updated and modified and are constantly under development. For instance, in 2015, at the beginning of the CDIO transition, during one of the recurring data collection activities with students, a student stated: "The projects are very relevant, but there was an overwhelming sentiment within numerous groups that given such broad prompt they would not be able to deliver an insightful solution within the window of 8 weeks. This carried the feeling of pointlessness in pursuing bold projects." This statement was a wake-up call about the need to rethink the collaboration with the companies in the project to identify suitable project descriptions for the 8-week window. It also suggested migrating from large, open-ended problems to more manageable issues that still maintain a sufficient level of ambiguity in the description to exercise the Design Thinking toolbox (which was at the core of the course). Similarly, more students in the same context stated: "The course would had been much more instructive for all groups if, for example, we received a "case" assigned to which all background-details were to be able to develop further and come up with a solution". This further pointed to the need to reformulate the material given to the students during the project kick-off phase, preparing a more detailed design brief. Under such dynamic circumstances for both data collection and contextual conditions, it is not possible to define a scientifically sound and stable data collection sample to derive a validated measurement of the impact of the operationalization of the different lessons learned. Nevertheless, those can be regarded as practical recommendations for teachers and educators starting the journey toward CDIO-oriented courses and can be used as a platform to further discuss, and eventually validate, generalized approaches for CDIO transition and management.

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