AN EVALUATION OF CDIO APPROACH TO ENGINEERING EDUCATION

Raymond Lynch, Niall Seery and Seamus Gordon

Department of Manufacturing & Operations Engineering,
University of Limerick, Ireland
E-mail: raymond.lynch@ul.ie

ABSTRACT

The CDIO initiative is a strategic approach to engineering education modelled on the lifecycle of a product. The underlying assumption is that an engineer will need to take into account all aspects of a product or service. The CDIO approach has been growing in popularity and has been adopted in a number of Universities worldwide. This paper examines the CDIO philosophy in the context of a number of contemporary theories of teaching and learning such as constructivism and problem based learning. The CDIO approach consists of twelve 'standards' that are adopted by an educational institution. In this paper each of the standards are compared to aspects of an accepted educational theory. It was found that the CDIO approach correlates well when compared to these educational paradigms.

INTRODUCTION

CDIO stands for Conceive, Design, Implement and Operate. CDIO is an innovative initiative, which offers an alternative educational framework for producing better-prepared and highly skilled engineering graduates. The initiative aims to provide students with an education that stresses engineering fundamentals based on the life cycle of a product. During the life cycle of any product it goes through clearly defined stages. The CDIO initiative applies this framework to the education of its undergraduate engineers. The students learn to solve problems and complete projects following the same stages i.e. Conceive, Design, Implement and Operate.

The CDIO initiative was developed with the input from academics, industry, engineers and students. It was developed in such a manner that it is universally adaptable to all engineering programmes and for all academic institutions [1].

To improve the teaching and learning of engineering students, the CDIO initiative aims to make four important improvements;

- The program increases active and hands-on learning,
- Emphasises problem formulation and solution,
- Thoroughly explores the underlying concepts of the tools and techniques of engineering,
- Institute innovative and exciting ways of gathering feedback.

These improvements aspire to fully engage the engineering students in all the stages of a product life cycle.

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 also promotes curricular reform to include design and build projects, to coordinate and link other subjects in an interdisciplinary engineering course. It aspires to create challenging experiences in which students design, build and operate product systems. In addition, due to the innovative teaching styles, the initiative requires alternative assessment processes. It is essential that continual and thorough assessment be provided for the students and success of the program itself. CDIO has included an assessment process, which evaluates individual student learning and faculty teaching as well as the overall impact of the CDIO initiative. CDIO is an open architecture endeavour and is available to all University engineering programs to adapt to their specific needs[2].

1. The CDIO approach

The CDIO initiative was formed in direct response to feedback universities were receiving from industry on the qualities and skills they required graduating students to possess. 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[3]. They found that traditional teaching methods often failed to achieve the goals set out by industry and many education faculty alike. The CDIO initiative has recognised a huge variance between the skills required by industry and those that graduating students possess and contributes this to a lack of balance between engineering practice and engineering science[4]. Over the second half of the 20^{th} century there has been a very noticeable shift away from the teaching of applied engineering practice at third level, toward an engineering science based education. This trend has also resulted in a shift away from design and implementation of solutions to engineering problems which the CDIO hope to address through this new and expanding initiative. CDIO believes that traditional teaching methods often failed to address that pinnacle which separates engineering students from engineers. To address this, the initiative has introduced more problem and project-based learning for the students, which more accurately mimic real life engineering scenarios.

1.1 CDIO in terms of product Life Cycle

Engineers engineer is the underlying philosophy of the CDIO approach. In other words, they create systems and products that fulfil a specific need. It is therefore believed that engineering graduates should appreciate engineering processes and the development of products[4]. Equally important is that students develop the vital skills needed by engineers. Organisations such as IBEC and Boeing have stressed that graduating students need to possess skills such as; self-motivation, self-reliance, commitment to ongoing learning, initiative and creativity, a sense of personal responsibility, adaptability, the ability to work in teams, and good social interpersonal skills [5].

CDIO feel that through the use of their initiative, universities can better prepare engineering students for real world engineering scenarios. 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.

Stage 1) Conceive:

This initial stage involves defining the needs and problems to be solved and technology required, considering the enterprise strategy and regulations. Here they develop the concept, technical and business plans[1].

Stage 2) Design:

This stage focuses on creating the *design* i.e. the plans, working drawing, and algorithms that describe what will be implemented in completing the project.

Stage 3) Implement:

The *implement* stage involves transforming the design into the product solution. This includes manufacturing, coding, testing and validating.

Stage 4) Operate:

This is the final stage and involves operating the implemented product to deliver the intended function, including maintaining, evolving and retiring the system.

1.2 Emulating the CDIO approach in the training of engineers.
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. During the lectures students are introduced to new concepts and principles and develop a knowledge and comprehension of them. During the tutorials, students are given the chance to apply, analyse and synthesise this information and then during the labs students can further apply, form results and evaluate their findings. Once they have successfully completed this cycle then they proceed to introduce a new concept or topic. This structure follows closely that laid out by Bloom's Taxonomy[6].

This structure can often fail to fully develop the vital problem-solving and project-based skills required in real world engineering projects as suggested previously[7]. However as the CDIO initiative is universally adaptable, it can be easily incorporated into existing structures. It is usual to have to redesign the learning environment and activities to give a better fit to CDIO but for the most part the traditional structure of lectures, tutorial and labs may not be affected.

The CDIO approach can easily be integrated into any engineering program. (Conceive – Lectures, Design – Tutorials, Implement – Labs, Operate – Labs).

Sample Case Study;

The CDIO initiative can be illustrated by the following case study of a successfully introduced program at Singapore Polytechnic, school of electrical and electronic engineering[8]. On becoming collaborators they decided to introduce a project-based program in 2003. There projects were developed using CDIO theories where students worked through conceive, design, implement and operate stages.

<u>Groups Involved in the Program;</u>

As part of these projects, classes of 20 students were required to build an aircraft that comprises sensors and control algorithms. Three cohorts of students completed this project in 2003. Separate to this main project, students were also required to complete small scale problem-based learning projects. For theses projects, students were expected to build creative artifacts based on control and sensor theories. A specific requirement of each project is that students have to develop a control system that detects a sensor reading and then as a result generates an effect, using the required actuators. For the purpose of these smaller projects, the class of 20 students in each cohort was divided into six groups of three or four students each.

<u>Aims of Program;</u>

This programs aims to provide students with a more balanced and holistic education by integrating the teaching of (a) disciplinary knowledge with (b) people and process skills and (c) values and ethics. This new program promotes creativity and authentic learning. The aim is to help students acquire desired learning habits such as resourcefulness, learning to learn and also to increase students' motivation to learn.

<u>Implementation of Main Project;</u>

This project forced students to work as part of a team, which given the shear size of the project and the work-load involved, they would have to work cooperatively if they were to be successful in completing the project. Students first had to come up with or *Conceive* ideas and solutions to the problem. They then proceeded to design the aircraft using working conceptual sketching, drawings, parametric modeling software, circuit drawing etc, and paying attention to aerodynamics, material, joining processes, costs, time etc. At this stage a model of the aircraft is produced to assess the success of their design. Once a satisfactory design has been produced, the students then begin to make the project, using their combined skills and the strengths. On completing the project the students will proceed to operate and test their aircraft. This follows the life cycle of any product and provides the students with clearly distinct stages to follow, developing necessary skills along the way.

2. Relevant Educational Theories

Constructivism;

The CDIO initiative can be related to a number of educational theories and approaches. One such theory is that of *Constructivism.* Educational philosophers have long seen constructivism as fundamental to good educational practice. The term constructivism refers to the idea that learners construct knowledge for themselves and meaning as they learn. Constructing meaning is learning and each individual constructs meaning differently depending on their individual characteristics, motivations, previous knowledge and experiences. If one is to accept the above statement then the consequences of this are twofold:

1) In thinking about learning and good educational practice, the focus must be on the learner.
2) There is no knowledge independent of the meaning attributed to the experience by the learner, (or community of learners as the case may be).

Constructivism emphasises the importance of one learning from their own experiences, building on their previous knowledge and using what they have previously learned and adapting this to solve new problems through assimilation[9].

Behaviorism;

A second educational theory very applicable to engineering education is that of behaviorism. Behaviorism is all to do with how one responds to and interact with their environment. At its most basic, behaviorism suggests that many of ones voluntary responses are strengthened when they are reinforced or rewarded and weakened when they are either ignored or punished. In 1938 B.F. Skinner develop the theory of "operant conditioning", the idea that we behave the way we do because this kind of behavior has had certain consequences in the past[10]. It refers also to the fact that one learns to operate on their environment in order to obtain or avoid a particular consequence.

Skinner charges that all mental activity is a form of a behavior and as such responds to something non-behavioral. This something non-behavioral is the environmental stimuli and ones interactions with, and reinforcement from, that environment. Therefore the significance of behaviorism is that it proposes that our actions can influence the behavior and thus learning outcomes of others. It allows one to inspire certain best practices and behaviors such as correct workshop practice and adherence to workshop safety in others.

Problem-Based and Project-Based Learning (PBL);

One vehicle for the introduction of constructivism into an engineering program is problem-based and project-based learning. Problem-Based Learning (PBL) combined with technology can be used in engineering programs to implement constructivism by providing an instructional method that requires learners to develop solutions to real life problems[11].

PBL has its origins at McMaster's' Medical School in the 1960's. Faculty developed PBL as a solution to the perceived need to produce graduates who were prepared to deal with the new information explosion, and still think critically and solve complex problems[6]. Problem-based learning has since been successfully adapted for the teaching of engineering students at third level. Problem-solving based programs are founded on constructivist principles and are most likely to foster meaningful learning. In addition they will encourage students to be active learners and to reflect on their experiences and begin to construct a mental model of the concepts involved. It will also provide students with complex tasks that are situated in real-world settings and require them to set out learning goals and work in cooperative groups with a significant amount of social interaction. One can see clear links between these attributes of PBL and the desirable qualities described previously.

In addition to problem-based learning, recent research from cognitive science also advocates the use of project-based learning. Project-based learning provides structure to students by giving them a project or problem to work on, along with project goals and deadlines. Marx et al [12] identified the following key components of project-based learning for Science.

- Driving Questions.
- Feasible real-world investigations.
- Tangible products for students to complete.
- Group collaboration and social interaction.
- The use of technology tools wherever possible. (i.e. parametric modeling, spread sheets, power control algorithms PCA's, programmable logical controllers PLC's etc).

3. CDIO Standards

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. Seven of these standards are seen as essential (highlighted by an asterisk below) and must be met before a program can be considered as a CDIO program.

Standard 1) - CDIO as Context*

In order to meet this standard the University must formally adopt CDIO as a strategic approach to teaching, that is, that the concept of a product and system life cycle development and deployment – conceive, design, implement and operate – are the context for engineering education.

Standard 2) - CDIO Syllabus Outcome*

The specific learning outcomes or learning objectives, the knowledge, skills, and attitudes intended as a result of engineering education are codified in the CDIO syllabus.

Standard 3) - Integrated Curriculum*

This standard is designed to ensure that there is an integrated curriculum with mutually supporting disciplinary subjects.

Standard 4) – Introduction to engineering

An introduction course should be provided to introduce students to the framework of CDIO courses and engineering practice involved in product and system lifecycle.

Standard 5) – Design – Build Experiences*

The curriculum of any CDIO program must include two or more design and build experiences for students, including one at a basic level and one at an advanced level.

Standard 6) – CDIO Workspace

For the successful introduction of a CDIO program the physical learning environment must be capable of supporting and encouraging project based learning, social interaction and multidisciplinary education

Standard 7) – Integrated Learning Experiences*
Any program must include integrated learning experiences for the students that lead to the acquisition of disciplinary knowledge, as well as personal, interpersonal, project and problem-solving skills.
Standard 8) – Active learning
The initiative encourages teaching and learning based on active experiential learning methods.
Standard 9) – Enhancement of Faculty CDIO Skills*
It is vital that all faculty members are actively involved in the introduction of any new program and that all members understand the CDIO approach.
Standard 10) – Enhancement of faculty teaching skills
It is not sufficient to just improve faculty CDIO skills. They must also be able to pass these skills onto their students. Therefore it is vital that their teaching skills correlate with and facilitate this approach to teaching[13].
Standard 11) – CDIO Skills Assessment*
It is vital that one can assess student learning in CDIO skills as well as in disciplinary knowledge.
Standard 12) – CDIO Program Evaluation
These twelve standards are to be used as a system of evaluating a programme's success and provide feedback to students, as well as faculty members and other stakeholders for the purpose of continuous improvements.

4. Approach taken in evaluating CDIO

In evaluating the success of CDIO one must look at a programme that has been in place over a significant period of time. Linkoping University, Sweden has been involved in the CDIO initiative from the very beginning (2000) and was one of the founding members[14]. As a result, Linkoping is the ideal university on which to base any investigation. One must first evaluated whether or not Linkoping meets the standards set out by the CDIO. If it meets these standards then it will be further investigated to assess its effectiveness as a CDIO program with its correspondence to good education practice and theory.

In developing a CDIO based program at Linkoping a board of studies for engineering education was first set up including members of faculty, industry and the student groups[14]. They planned seminars around CDIO standards and Syllabus in order to get the CDIO view of education and program goals. It is clear therefore that they meet standard 1) – CDIO as context.

<u>Those involved in the Programme;</u>

They decided to introduce the CDIO concept to three of their programs at Bachelor level. These programs are electrical systems engineering, media and communication technology and logistics engineering. Each program has a sequence of three project courses progressing in difficulty, emphasising personal skills, interpersonal skills and the CDIO view of engineering. The university provides engineering programs at both bachelor level and master level, with the bachelor level programs run over three years. Therefore each year will include a project module with the first year including a project module designed to be an introduction to engineering for the students. Each year a total of ninety new students start the courses and they all share a core of common modules including mathematics, computer science, transform theory, computers and signal processing.

Implementation of the Programme;

For the project modules, project groups are formed from all three programs in order to get the students to work in teams and develop their interpersonal skills and to make it more realistic. With students from across three different programs working on the projects, they can each provide knowledge from their respective areas. The last design-build-test module in the final year is intended to realise as many of the projects in co-operation with local industry with the intent to better prepare students for future career work. Examples of these projects include alarm systems, controlling an industry process, localisation of a storage site, optimisation of a transport route etc. Projects are designed to replicate real life engineering problems as best as possible and therefore give the students a better interpretation of what is expected of them in their future working environment.

Evaluation of the Programme;

It is clear that the engineering programs at Linkoping University meets the seven essential standards set up by the CDIO initiative. One must now evaluate the success of these programs and therefore CDIO. The success of this CDIO program can be assessed by applying what is known to be good educational practice and theory to the courses at Linkoping. The courses all provide the students with an integrated curriculum, which encourages the development of personal, interpersonal and problem-solving skills, as well as the acquisition of disciplinary knowledge. The use of both project-based and problem-based learning is evident throughout the three-year courses. Active learning is also encouraged throughout all and there is clear evidence of constructivist learning. Constructive learning by its very definition is active in nature and by getting the students to participate in and aid in the completion of “real-world” project, they become actively involved in the world around them. As a result, this gives the students more responsibility for their own learning through the careful guidance and supervision of faculty members, enabling students to better assimilate and apply the knowledge and skills they are learning. Students themselves become the main instigators of their own learning, which can lead to better motivation, social interaction and inevitably learning outcomes.

The courses have been designed with the input from industry, faculty members and students alike providing an integrated learning experience. Students are asked to complete tangible products through the use of feasible real-world investigations, group collaboration and social interaction. Clearly then this adheres to good educational practice and theory and better serves to achieve the goals set out previously. It was previously shown that industry desires more autonomous, self-reliant engineering graduates with good creative, critical thinking, problem-solving and also interpersonal skills. By handing over more responsibility for learning and development to the students themselves, one not only helps develop more autonomous students but also the skills required in “real-world” engineering scenarios. Once students leave college or university they are forced to work in an environment where they are responsible for their own actions, for the success or failure of a project, for their own ongoing learning which is present in all engineering careers (or any career for that matter). Therefore it is important to encourage such behavior while students are still at undergraduate level, where their learning and development can be monitored and supervised by faculty members.

Sources of Error;

To date little documentation has been provided on the assessment of student’s progress at Linkoping University or on comparing their progress to that of traditionally taught programs. Although in subsequent papers Linkoping University did make recommendations to overcoming barriers to CDIO and this did include improvements to assessment procedures.

The biggest problem facing the assessment of a CDIO program is that one is trying to measure human factures, for example; social interaction, improvements in motivation, pride in ones work, creativity etc. These are all extremely difficult to accurately measure using standard tests. However one solution to this would be to apply Kirkpatrick's' model for summative evaluation to the program in order to assess its validity. In 1975, Donald Kirkpatrick first presented a four-level model of evaluation that measures and evaluates the effectiveness of any training program[15]. These four levels are 1) Reaction, 2) Learning, 3) Behaviour, and 4) Results. While originally this model was designed for training in industry it can be easily applied to third level education programs. This model allows us to examine the assess structure itself. Traditional assessment structures measured students' ability to absorb and comprehend information and then reproduce this at a later date during an exam. This structure allows one to examine both the cognitive development of student and the development of human factures such as those mentioned previously.

CONCLUSIONS

In modern undergraduate engineering courses there is growing tension between two great needs. On one hand, there is the ever-increasing body of disciplinary knowledge that all students must command. On the other hand, there is a growing consensus that students must posses a wide variety of personal, interpersonal and system building skills that will allow them to deal with real world engineering problems. The CDIO initiative is attempting to address this and from the above case study it can be seen to very successful when correctly adopted and implemented in an undergraduate engineering course.

The CDIO Syllabus outlines a comprehensive set of goals and aims for any CDIO programme, in order to help develop a clear, complete and consistent set of detailed topics that facilitates the implementation and assessment of the programme[4]. In the syllabus, CDIO have outlined four main areas that engineers must be competent in. These building blocks of the syllabus are the knowledge, skills and attitudes necessary to conceive, design, implement and operate systems in an enterprise and social context [4].

The CDIO syllabus adheres to good educational practice and theories such as constructivism and project-based and problem-based learning. If one was to apply Blooms Taxonomy of learning to the CDIO syllabus[6]. The knowledge is developed at stage one of the syllabus *Technical knowledge and reasoning*. During the comprehension, application and analysis of the projects, students develop the *personal, interpersonal and professional skills* outlined in stages two and three of the syllabus. Synthesis and evaluation then takes place in the final stage of the syllabus; *conceive, design, implement and operate.*

Therefore when examined, a well-implemented CDIO program is a good fit and corresponds well with the education theories mentioned earlier. One can also see a clear link between the success of a program and how well it meets the twelve standards set out by CDIO, and therefore how well it adheres to good educational practice.

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