

**REVIEWING AND EVALUATING CDIO [CONCEIVE, DESIGN, IMPLEMENT,  
OPERATE]: AN EMPIRICAL APPROACH TO ENGINEERING EDUCATION  
CURRICULUM DEVELOPMENT**

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## **ABSTRACT**

This paper draws upon research conducted at Aston University which critically evaluated the issues surrounding the introduction of CDIO across the first year undergraduate curriculum in Mechanical Engineering and Design. From the induction of the programme, engineering education researchers ‘shadowed’ the staff responsible for developing and introducing the new curriculum. Utilising an Action Research Design, and adopting mixed methodological research techniques, the researchers worked closely with the teaching team, critically reflecting upon the issues arising in introducing CDIO into the curriculum. Drawing upon the emergent findings of the study, the paper discusses how Problem-Based Learning, in the shape of CDIO, can offer a viable alternative to traditional engineering education. In doing it adds to current debates in this area by showing how an approach based upon PBL not only enriches students’ learning experiences, but also challenges those responsible for programme planning and delivery.

## **INTRODUCTION**

Engineering has recently received much public attention with events such as the Mexican Gulf Oil Spillage and the Japanese Earthquake receiving worldwide press coverage, whilst other more longstanding problems associated with sustainability, pollution and global warming have long been on the public agenda. Based on the premise that by acting to shape the world in a manner that benefits humanity (RA.Eng, 2010), engineering provides an integral link between society and science. Key to this link is engineering education, which in providing the vehicle that society uses to attract, recruit, train and professionally develop engineers at all levels, has a vital role to play. This role is both in the future sustainability of the profession and also in the future prosperity of our society. Yet, whilst engineers are

increasingly called upon to solve some of the world's most complex problems, it is ironic that in the UK in particular, the profession is experiencing significant difficulties in attract new recruits. Although there can be no doubt that engineering offers an exciting and viable career, the question of how to convince young people of this, and in doing so increase the numbers of future engineers enrolling on university programmes, is something that both engineering education and the profession have yet to address (IMechE, 2009; Spinks et. al, 2006).

The need to equip students with a broad range of technical skills, competencies and abilities, whilst providing them with a broad theoretical grounding, and preparing them for the workplace, means that university level engineering education is in facing something of a trichotomous split (Lucena et al, 2008). To make matters worse, in the complex learning environment that is today's Higher Education Sector, many engineering programmes find themselves having to deal with high levels of student attrition (DIUS, 2008; NSF, 2009). Furthermore, complicated by difficulties in recruiting new students onto programmes, problems indicative of high student 'drop-out' rates are augmented by public perceptions of the profession as being one in which inequalities in gender, social class, and ethnicity are the norm (Gill et al, 2008; NSF, 2009). Indeed, it may be argued that commonly held stereotypes of what 'an engineer' is [a white, middle-class, middle aged, male] do little to help recruitment into the profession. This means that many 'potential future engineers' do not even begin to consider engineering as a career choice. Added to this is the fact the traditional pre-requisite subjects of physics, maths and chemistry are generally not favoured by today's generation of 16-18 year olds (Jones et al, 2000; Dickens & Arlett, 2009) who find them overly demanding and difficult.

If current trends of low recruitment into the profession, and high attrition rates on engineering education programmes, continue then the outlook for engineering and engineering education over the next two to three decades appears to be increasingly bleak. It

is clear therefore, that as a discipline, engineering and engineering education need to work together to redress the balance. Failure to do could mean that in the relatively near future, the UK will face unprecedented shortages of engineers (IMEchE, 2009; Spinks et. el, 2006) and engineering education in the UK could find itself struggling to survive. This could have devastating effects for UK society as a whole.

### **CDIO: A SOLUTION TO ISSUES IN ENGINEERING EDUCATION?**

Like the rest of the UK Higher Education Sector, engineering education is facing unprecedented changes to the way it is financed with the coalition government drastically cutting funding to all universities and colleges. Furthermore, government and industry expectations that Higher Education will ‘produce’ large numbers of work-ready, flexible and highly qualified graduates means that all educators are increasingly finding themselves having to ‘produce more with less’. Contextualised by this highly pressured financial environment, Aston University School of Engineering and Applied Science decided to radically change its pedagogical approach to engineering education – introducing CDIO (Crawley, 2002), across the first year curriculum for all Mechanical Engineering and Design students in 2010-2011.

Identified as *‘an innovative framework for producing the next generation of engineers’* the founding principles of CDIO are such that it encapsulates *‘... a commonly shared premise that engineering graduates should be able to: Conceive – Design – Implement – Operate complex value-added engineering systems in a modern team based engineering environment to create systems and products’* (CDIO, 2011). With regards to Aston University, CDIO enables the teaching staff to engage the students through providing a practically relevant and academically grounded learning experience. The University website provides students with the rationale for teaching with the CDIO approach ... *“... the essence*

*of you becoming an engineer or designer is not only dependent on you developing technical knowledge but also being able to combine this with practical engineering skills, social awareness, team and project management abilities, and competencies in many other fields to solve engineering problems” (Aston University, SEAS, 2011).*

The Aston University approach to CDIO was purposefully developed to take account of students’ learning needs in a manner that both meets industrial expectations whilst capturing the high levels of theoretical and practical knowledge expected of a contemporary university level engineering programme. Additionally, the curriculum was designed to provide economically viable and practically relevant active learning experiences that would both engage and challenge students whilst enthusing them about engineering. The module, which is taught in a bespoke CDIO laboratory, is taught over a 9 hour period one day each week. In addition to this students are required to dedicate a further 14 hours per week on CDIO related activities (both practical and theoretical learning). More traditional lectures and tutorials supplement the curriculum as appropriate to the discipline. The module is taught by 4 engineering lecturers, all of whom are highly committed and enthusiastic about the approach. They, in turn, are supported by ‘guest’ lecturers and technical-support staff.

In order to evaluate the pedagogical effectiveness of the CDIO approach, two independent researchers were employed to critically analyse the overall educational and practical value that CDIO adds to the student learning experience. It is this research that forms the basis of this paper.

## **METHODOLOGY**

Utilising mixed methodological research approaches, and following an Action Research Design, the researchers followed the programme development and delivery right from its onset – making a contemporaneous record of events, experiences and issues as they arose.

This paper captures the first phase [Year 1] of a longitudinal study which is aimed at critically evaluating the CDIO approach as it is rolled out across all 4 years of the Undergraduate Programme in Mechanical Engineering & Design. By undertaking a ‘real-time’ analysis, the study will provide a unique record and analysis of the students’ and faculty’s pedagogical experiences as they occur.

The first stage of the research involved non-participant observations. An observational framework was drawn up and observations scheduled during 12 different CDIO sessions occurring over the first two terms of 2010 / 2011. It was decided that the lead researcher should undertake these observations as he was familiar with the engineering context and content of the programme – and so could focus on the pedagogy and research without being distracted.

During the middle of Term 1 a quantitative survey was administered to all students. The response rate was 65%. The data was analysed and the findings reported directly to the teaching team – thereby providing them with an early indication of students’ perceptions of the approach. This meant that they were able to identify potential difficulties and deal with them in a timely manner. Building on the findings of the observations and survey, a qualitative questionnaire was administered at the end of the second term in April 2011. Comprising ten ‘open’ questions, all of the students were surveyed. The response rate was 73%.

## **OBSERVATIONAL FINDINGS**

The observations provided the ideal means by which the researchers were able to gain first-hand insight into the issues and experiences of students and staff as the CDIO approach unfolded. The observational framework was grounded in pedagogical research and utilised an ethnographic approach. The observational data was analysed utilising a grounded theory

approach (Strauss & Corbin, 1990). Four distinctive concepts were identified in the analysis of the observational data: people: pedagogy: process: and product.

The first concept 'people' captured staff anxieties with regards to the practicalities of offering such an intense learning and teaching experience. These concerns were not unfounded. Once the programme began, high levels of physical, mental and practical stress were observed amongst the staff. The nature of the CDIO approach means that it is not an easy option for staff. Its student focus requires those responsible for teaching to be continually mentally astute, able to deal with students' constant questioning and high expectations.

One of the major issues identified during the observations related to the difficulties of 'large group' teaching. Although the university provided a bespoke CDIO laboratory, which was ideally suited to the practical activities, the 'instructional' part of the sessions provided difficult as the acoustics in the room were not ideal. This was observed to be equally frustrating for students and teaching staff.

The second concept 'pedagogy' captures the challenges of balancing the requirements of an active learning approach with an engineering content and context. During the observations it was noted that towards the end of Term 2 some of the staff appeared to find the need to be constantly innovative more than a little challenging. Whilst this was overcome by the staff working together to develop new, academically grounded and practically relevant projects, the fact that they had to work with limited financial resources proved more than a little frustrating at times.

A second pedagogical issue reflected difficulties with assessment and feedback. A range of formative and summative assessment techniques were used during the module including instant electronic feedback systems, and the keeping of individual logs. The use of electronic feedback systems was observed to be highly successful in keeping students (and

staff) engaged. Other methods of assessment proved to be less successful. Most notably, difficulties were observed in the provision of individual feedback. The large group size meant that much of the feedback tended to 'generic' in nature identifying commonly experienced problems and issues. Whilst this worked for most of the students, it was evident that a minority were not able to contextualise and apply 'group' feedback to their own work.

A third pedagogical issue reflected students' experiences of group work. Whilst the majority of the groups 'bonded' and were observed to be cohesive and supportive in nature, a few students failed to 'pull their weight' causing friction and tension within in their group.

Although group work caused some predictable difficulties, the 'process' of CDIO, breaking the sessions into the four distinctive stages of *Conceive, Develop, Implement* and *Operate* proved highly successful. The students were observed to quickly adopt, and adapt to, the active style of learning engendered by CDIO. From an engineering perspective, each stage was clearly distinctive, comprising separate but integrated theoretical content and practical activities.

The final concept 'product' captured three separate strands linked with the development and delivery of CDIO: resources; technology; and production. The Aston approach has been developed at a time when the need to be 'financially astute' was of paramount importance. Resources for the activities were, on the whole, locally acquired from recycled materials. This enabled students to learn about the basics of engineering in a practical, problem-solving yet financially shrewd way.

The second strand within the 'product' concept was 'technology'. This related to the electronic feedback system. That this was not always totally reliable caused frustration for staff and students alike. This meant that on more than one occasion staff were required to 'think on their feet' and improvise. Whilst this was undoubtedly more than a little

exasperating, that students were able to witness their lecturers finding practical solutions when the technology failed to work was an important lesson in engineering practice.

The final strand forming part of the ‘product’ concept related to ‘production’. In each session the students were required to make something ‘real’ and then test it. This was observed to be a successful and engaging way of learning. It enabled the students to actively test theoretical and practical perspectives and in doing so link the two. They were observed in their groups discussing the various options around each project – relating their choices to a range of theories and concepts. However, on the negative side, varying levels of commitment were observed with some students notably contributing more than others.

## **SURVEY FINDINGS**

In administering the survey during the first term, the researchers aimed to gain insight into the students’ previous learning experiences. In addition to providing ‘benchmarking’ data, this meant that the programme leaders were subsequently able to adapt their approach accordingly.

Likert Scales were used to gain a breadth of opinion and insight. Questions were focused into 4 distinctive categories: Previous learning experiences: Expectations of the University learning environment: Expectations of the ‘added value’ of University: Perceptions of the first few weeks of participating in CDIO

The survey was developed in such a way so as to deliberately reflect the fact that around 80% of the students had entered university straight from school. It captured students’ perceptions of how useful they found previous learning approaches in preparing them university and revealed that ‘problem-solving’ was their previous preferred learning approach, with ‘designing things’ and ‘making things’ also popular. This finding was not entirely unexpected given the discipline choice of the sample group. ‘Formal lessons with 21 or more students’ proved to be the least favoured approach.

Students were asked to indicate their level of agreement in respect of the types of learning approaches they expected to experience at university. The study revealed that the students' least expected 'essay type' assignments. This finding possibly reflects typical pre-university education where 'long' essays are not generally part of the curriculum (particularly in the sciences). The vast majority of students in the sample were, more or less, completely new to engineering, with their previous exposure being limited to participation in competitions, or to familial linkages (usually fathers, grandfathers, brothers or uncles who are engineers).

Students were then asked about their expectations of how university would prepare them for employment. Not surprisingly given the high costs of higher education, the study revealed that the students had high expectations that the programme would prepare them for the 'world of work'. In many respects, this in itself highlights the importance of CDIO in that it promotes employability by giving students 'real-life' skills and experiences.

The final part of the survey looked specifically at the students' perceptions of participating in CDIO. The value of CDIO in helping students' link engineering practice to theory, and theory to practice was evident in the study findings. Likewise, its value in promoting team-working, independent thinking and problem solving were all indicated in the findings

The questions in the qualitative questionnaire provided the students with the opportunity to give their views in a more open manner than afforded by the earlier quantitative survey. The questions focused on the students' perceptions of CDIO as a learning approach and covered all aspects of the learning experience. Typically, most of the responses took the format of a single sentence.

## **DISCUSSION AND CONCLUDING REMARKS**

The emergent findings from this study suggest that the engineering students entering undergraduate programmes prefer ‘hands on / problem-based’ approaches to learning. It also reinforces previous study findings which argue that on the whole, students prefer working in small groups rather than attending large lectures. The CDIO approach allows teaching staff to capitalize on such preferences, and in doing so make the most of students’ natural predispositions towards ‘practical’ learning. By providing an active, problem-based, learning environment in which theory can be linked to practice in a realistic and understandable manner, CDIO enables students to experience a range of engineering problems in a ‘safe’ and ‘controlled’ environment. Indeed, there can be little argument that CDIO provides students with the opportunity to develop high level engineering specific skills and also offer them the means by which they are able to acquire ‘softer’ transferable competencies such as team-working. In this manner the PBL nature of CDIO is crucial to promoting the students’ employability and employment prospects.

From an educational management perspective, it would appear that the problem-based nature of the CDIO approach has provided the means by which the university has begun to address issues of retention in engineering education. By providing a positive and exciting learning environment the ‘drop out’ rate has decreased from an average of 10% of the cohort for each of the preceding three years (from the academic year 2006/ 07 through to 2009/ 10), to 2% of the cohort so far this year.

In conclusion, it should be noted that CDIO does not provide an easy option. For the staff, the academic and theoretical practicalities associated with offering such an intense learning experience can prove demanding. Whilst for students, CDIO provides an innovative way of learning that does much to prepare them for their future careers. What is clear is that the next four years will be both exciting and challenging for both staff and students alike.

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