

An Investigation into the Adoption of CDIO in Distance Education.

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Abstract

The Conceive, Design, Implement and Operate Initiative (CDIO) uses integrated learning to develop deep learning of the disciplinary knowledge base whilst simultaneously developing personal, interpersonal, product, process and system building skills. This is achieved through active and experiential learning methods that expose students to experiences engineers will encounter in their profession. These are incorporated not only in the design-build-test experiences that form a crucial part of a CDIO programme but also in discipline-focused studies. Active and experiential learning methods are, of course, more difficult to incorporate into distance education. This paper investigates these difficulties and the implications in providing a programme that best achieves the goals of the CDIO approach through contemporary distance education methods.

First, the key issues of adopting the CDIO approach in conventional on-campus courses are considered with reference to the development of the CDIO engineering programmes at the University of Liverpool. The different models of distance based delivery of engineering programmes provided by the Open University in the UK, and Deakin University and the University of Southern Queensland in Australia are then presented and issues that may present obstacles to the future adoption of the CDIO approach in these programmes are discussed.

The effectiveness and suitability of various solutions to foreseen difficulties in delivering CDIO programmes through distance education are then considered. These include the further development, increased use and inter-institutional sharing of technology based facilities such as Internet facilitated access to laboratory facilities and computer aided learning (CAL) laboratory simulations, on-campus workshops, and the development of a virtual engineering enterprise.

1. Introduction

A significant feature of the Conceive, Design, Implement and Operate Initiative (CDIO) is the use of active and experiential learning which arguably is best delivered

through proximal learning. However there is a need for programmes delivered by distance education. The authors from the three distance education universities recognise some elements of CDIO are already embedded in their programmes; nevertheless this paper presents a preliminary joint investigation into the issues of developing distance based programmes that more fully meet the goals of CDIO. In Australia and the UK, mature students are a major growth area in higher education (ABS 2006; Warwick 1999). They include not only those who did not have the opportunity to go to university when they left school but also the increasing numbers changing career direction, studying for higher degrees or engaged in continuing professional development to update or broaden their education (Ferguson, 1998; Brodie 2007). Distance education enables such learners to upgrade to professional engineers without taking a career break.

However Australian studies (McInnis and Hartley 2002; Long and Hayden 2001) have shown that patterns of on-campus student engagement with study have changed, especially when compared to the time most current institutional (education and professional) administrators might have completed their undergraduate studies. Full-time students now must make trade-offs between employment and study for a range of reasons. As a result the modern study-plus-work arrangement of the typical on-campus student is moving closer to the work-plus-study pattern of the typical off-campus student. Many 'full-time' students have a limited on-campus experience with 57 percent indicating they spend little time on-campus other than for classes (McInnis and Hartley 2002). Long and Hayden (2001) report that 65.8 percent of all engineering students were in paid employment during the semester, working an average of 16.2 hours per week and 33 percent of all working engineering students frequently miss classes.

In response, traditional universities are increasingly adopting 'blended learning' that combines a range of teaching and learning activities that might traditionally have only been associated with one end of the continuum (Muirhead 2005). However there are also other drivers for this change. They include facilitating participation by a more diverse student body, a desire to increase student ownership of their own learning and pressures on lecture space.

Therefore, most students previously categorised as either on-campus or distance students, are now positioned somewhere along a continuum between these two forms of educational delivery. Thus, through the adoption of blended learning, most traditional universities will also be impacted by many of the issues considered in this investigation.

In this paper we first provide a brief overview of the essential elements of CDIO and describe key elements in the adoption of CDIO in the programmes of the University of Liverpool. We then describe the models of distance-based delivery at Deakin University and the University of Southern Queensland (USQ) in Australia and the Open University in the UK (UKOU) before considering the effectiveness of various distance-based approaches to the delivery of CDIO engineering programmes.

2. CDIO

Conceived during the 1990s at the Department of Aeronautics and Astronautics of the Massachusetts Institute of Technology (MIT), CDIO was launched in 2000 simultaneously at MIT and three Swedish universities and has now spread throughout the world. Its primary aim is to refocus engineering education to enable students to be more successful engineers through much closer alignment of the degree programme to the four phases of the product, process or system lifecycle: conceive, design, implement and operate. CDIO is based on recognising the full

range of involvement of professional engineers and so provides the most appropriate setting for the development of graduate attributes. The stated aim of CDIO is:

‘to educate (engineering) students to understand how to Conceive-Design-Implement-Operate complex value-added engineering products, processes and systems in a modern, team-based environment’ (Crawley, Malmqvist, Ostlund and Brodeur, 2007).

The approach involves:

- A CDIO Syllabus customised from stakeholder surveys that adds to the programme defined technical knowledge a range of personal, interpersonal and professional attributes as well as the key elements of CDIO in the enterprise and societal context. The emphasis to be given to each of the attributes is to be determined by each university with local stakeholders (CDIO Standard 2);
- Programme curricula developed around mutually supporting disciplinary subject streams that reflect the practices, skills, knowledge, and values of the full range of professional engineering practice (through the context of product, process and system conception, design, implementation and operation - CDIO Standard 1). The curricula are interwoven with activities that develop graduate attributes such as personal and interpersonal skills as well as product, process and system building skills (CDIO Standards 3 and 7);
- An introductory study unit ‘Introduction to Engineering’ providing the framework for engineering practice that provides a broad outline of the role of an engineer and enables the student to engage in the practice of engineering through problem solving and design both individually and in teams (CDIO Standard 4);
- Engineering based experiential learning through design-implement and hands-on learning experiences provided both in the classroom and in specially developed learning workspaces (CDIO Standard 5);
- Active and experiential learning incorporated into the disciplinary subject streams beyond design-implement experiences (CDIO Standard 8);
- The redevelopment of student workspaces to facilitate the four lifecycle phases of CDIO (CDIO Standard 6);
- The use of best practice engineering education methods;
- Continuous development through support and the sharing of ideas between CDIO universities;
- The flexibility to adapt to changing professional needs; and,
- A comprehensive process of learning assessment and programme evaluation (CDIO Standards 11 and 12).

3. The application of CDIO at the University of Liverpool

In 2002 the Department of Engineering at the University of Liverpool^{viii} developed a ten-year plan designed to change the way Engineering was taught at undergraduate level, and decided to adopt the CDIO context. At the time this embraced degree programmes in Mechanical, Aerospace, Materials and Manufacturing Engineering. In 2004 this brief was extended to programmes in Civil Engineering, within a new, enlarged, Department of Engineering. All programmes were to be re-launched in 2008/09 under the brand “The Liverpool Engineer”, and the first “Liverpool Engineers” will graduate in 2011 (BEng) and 2012 (MEng).

It was seen as inevitable that an evolutionary approach must be taken, for two principal reasons: Crucial new elements of the curriculum could not be delivered simultaneously, requiring development time and modification following pilot trials and feedback. Equally as important is the time necessary to change the attitudes and teaching skills of academic staff. It is no exaggeration to say that a period of ten years is desirable to enable teaching staff to become comfortable with the methodologies and pedagogic potential of active learning and cooperative learning. Prior to the adoption of the CDIO context, several active techniques and helpful pieces of technology were already in place at Liverpool. These included a Virtual Learning Environment (based on Blackboard®), an electronic Personal Development Planning tool (LUSID) and a Personal Response system with a large set of clickers. Each of these has of course continued to develop during the Liverpool Engineer programme.

The CDIO approach suggests that all programmes should include an ‘Introduction to Engineering’ module in the first year (CDIO Standard 4). Such introductory modules should seek to illustrate the roles and responsibilities of professional engineers and the people with whom they interact; to illustrate how disciplinary knowledge is applied in the solution of engineering problems; and to target the development of knowledge, skills, and attitudes essential in professional engineering.

The Liverpool Introduction to Engineering module has been developed to reflect these principles. It involves 150 hours of student learning over two 12-week semesters. The module is structured around a team-based design-build-test (DBT) exercise (CDIO Standard 5) and deploys a range of teaching approaches (CDIO Standard 8) in the coverage of key syllabus topics (CDIO Standard 2). The module is structured and scheduled to provide an integrated learning experience that requires students to apply learning from other engineering science modules within their programme (CDIO Standard 7). Within the module are three key active elements: The Two Week Creation (TWC) and the 3D Computer-Aided Design (CAD) training course are considered ‘immersive learning experiences’ because students devote 100% of their time to them and participate in no other activity for their duration. The Ice-breaker exercise is considered ‘semi-immersive’ as students are required to devote 50% of their time to its completion. This required the clearing of the student timetable for 3.5 weeks within their first year (of 24 weeks), but early evaluation of these exercises indicates that they have been successful in their aims, without significant impact on other first-year work. At the end of their first year, engineering students are competent users of Pro-Engineer, have participated in two team-work exercises and have built and tested a bridge and either an aircraft or a car.

Further active elements are being incorporated into every module offered by the Department of Engineering. Every member of teaching staff has been challenged to enrich his/her modules by introducing an active component. Examples which have been successful so far include the development of computer-based “pre-lab” exercises designed to familiarise students with equipment and techniques before

they embark on laboratory classes; the development of virtual projects so that techniques of project management can be practised before real projects are started, and the development of a Problem Based Learning (PBL) module around flight handling qualities.

The final “capstone” project, spanning either one or two years, brings together strands of learning from throughout the student’s programme and offers an opportunity to deploy personal and professional skills within a team context. An individual research project is also undertaken by every student, based in one of the Department’s research laboratories.

There are a number of significant aspects of the methods used to stimulate change during the Liverpool Engineer project. Some of these were deliberate while others were serendipitous. The two most important features were the identification of the umbrella “Liverpool Engineer” (LE) project, and its leadership by two consecutive Heads of Department who both shared a vision of the project’s mission and led by personal example – changing their own modules at an early stage in the project. Other helpful features included the creation of a single Department within which all the LE programmes are delivered, the running of regular “away days” during which staff are encouraged to engage with new styles of learning and teaching; the prior existence of a few good exemplars of active modules; the presence within the Department of a team writing professional educational software (MATTER, www.matter.org.uk); wholehearted CDIO membership and participation, with a large number of staff encouraged to attend CDIO meetings and conferences across the world, and thereby appreciate that they are not alone (14 staff have been to CDIO meetings elsewhere, while most attended a dedicated workshop run by international CDIO leaders at Liverpool in 2005); the appointment of full-time project staff, together with an associated budget, with a brief to support and manage the process of change, and; the fact that the Department has been able to appoint 16 new staff (out of a complement of 51) since the project was initiated. These colleagues have entered a Department where the CDIO context is the norm, and for them less change is implied.

A further important validator for change is the Department’s Industrial Liaison Board. The input of many industrially-based friends, who universally endorse the direction of movement and are able to offer significant practical help, is encouraging for staff and students alike.

A final extremely helpful feature is that substantial refurbishment of the department’s buildings and laboratories was undertaken starting in 2003 with completion in 2008. Although this is in the short term disruptive, it has meant that new flexible teaching spaces could be devised and built, which are better suited to active learning than raked lecture theatres or fixed-bench laboratories. An associated capital sum to invest in new equipment has helped to encourage staff to develop new activities for students, and will enable the teaching laboratories to reflect the current state of the art.

4. Models of distance based delivery

Before considering the possible limitations of distance education in the delivery of CDIO engineering programmes we will present the different models of distance delivery used by the three distance education universities of four of the authors.

A key consideration of all distance based engineering programmes is that the off-campus students are usually employed full-time and studying part-time and so generally are not able to study more than half a full-time equivalent load. This factor

must be considered when developing the curriculum around mutually supporting disciplinary subject streams. Thus if two study units are developed as mutually supporting it may be necessary to merge them into one unit with a credit value equal to the two merged units.

4.1 Australia

Deakin University and USQ are the main Australian providers of distance based engineering programmes and are accredited by Engineers Australia (EA)^{viii}, the professional body for all engineers in Australia. Both provide dual proximal and distance-based programmes.

Deakin University was formed in 1977 as a dual proximal and distance-based university. It had early strong associations with UKOU, however engineering was taught only in on-campus mode. The engineering school was closed in the early 1980s but strong campaigning by local industry and the local branch of EA led to its rebirth in 1991 as a dual mode School of Engineering and Technology. In 1993 Deakin University became the first Australian university to offer provisionally accredited engineering degrees primarily by distance education. EA, initially reluctant to accredit a full distance-based engineering degree programme, imposed a requirement that distance-based students study on-campus for the capstone year. However before any off-campus student reached the capstone year, developments in the use of a range of technologies to support engineering teaching at Deakin University led EA to drop that requirement.

For every study unit study guides containing the lecture notes are mailed out to the off-campus students. A Blackboard® based unit web page provides additional study materials including the study programme, assessment details, the assignments, tutorial materials and a student discussion facility. This forms the minimum level of learning resources for any study unit.

Additional web based resources may include iLectures or the lecture slides, on-line quizzes or assessed tests, chat rooms (including 'whiteboard') providing synchronous communication for team-based design, Eluminate Live®, direct Internet access facilitating student remote control of laboratory experiments and/or machine tools (Ferguson and Florance, 1999), and web links to useful related sites, the library and university licensed CAD and software. Other useful software (including in-house developed computer aided learning (CAL) programs) is included in the 'Deakin Learning Toolkit' digital versatile disc (DVD) sent out annually to all Deakin students. Other mailed out learning resources may include home experiment kits; video and CAL simulations of laboratory experiment; and videos that provide physical demonstrations of concepts to the off-campus students.

USQ also provides a similar range of support for distance students in terms of student material. Pastoral care is provided by the Distance Education Centre (DEC) which has Regional Liaison Officers and office support in areas where there are large numbers of USQ Students. DEC also provides and monitors communication channels between students and academics. This ensures basic administration matters can be dealt with effectively by DEC and when students require consultation with an academic, DEC ensures a timely response is received.

In 1997 there was a fundamental shift in EA accreditation policy from a course content focus to a graduate attribute focus. Within a few years they introduced an accreditation requirement that all students of engineering programmes that are offered in distance mode must attend a two week on-campus professional practice workshop every full-time equivalent year. This requirement applies to both proximal

and distance education students of programmes that are offered in distance mode. A further EA requirement is that all engineering students must undertake at least twelve weeks work experience in an engineering environment during their undergraduate programme.

The engineering student mix at Deakin University varies with the engineering discipline but overall the on-campus students now increasingly form the largest cohort of students. This includes a small number of full fee paying on-campus international students. The EA on-campus requirement impacted unfavourably on off-campus enrolments. There are also a small number of students studying Deakin University engineering programmes through overseas partner institutions. In contrast over 75% of the engineering students at USQ study through distance or on-line methods.

USQ offers a range of fully articulated engineering qualifications including a two year Associate Degree, a three year Bachelor of Technology and a four year Bachelor of Engineering^{ix}. These are offered across a range of nine majors e.g. electronic and electrical, mechanical, civil, agricultural, environmental, mechatronic etc.

The distance student cohort is largely mature aged, working in industry. Due to the diverse entry paths offered by the faculty many students do not have the normal expected levels of study in math and physics. However they do have a wide range of both industry and practical experience which complements the more theoretical base of the younger students.

Teamwork which encourages students to share knowledge and experience through peer assistance and mentoring has a growing place in the USQ curriculum. In addition many of the foundational courses are being tailored to cater for student diversity by allowing students to extend existing knowledge and acquire new knowledge depending on individual prior learning experiences. The most successful of these curriculum developments are a strand of Problem Based Learning courses. For the distance students they work in a virtual, multidisciplinary team using a variety of communication technologies to solve open ended contextualised problems. Teams work across time zones both across Australia and internationally. These courses deliver not only required technical knowledge but also the key graduate attributes of teamwork, communication skills and problem solving.

4.2 UK

The UKOU was established in 1969 and has included aspects of engineering in its curriculum since the early 1970s. With the exception of full-time research students, the University teaches entirely by distance education. The very pure modular curriculum historically imposed few restrictions on learners' choice of subjects to include in their bachelors degrees before the introduction of 'named degrees' at the end of the 1990s. Until this time, therefore, it was not possible to offer a degree programme for engineering accreditation, although a number of Engineering Council UK (ECUK) licensed bodies published narrowly-specified profiles of routes to a UKOU honours degree for those wishing to apply for registration as Chartered Engineers. At the time of writing, two applications for accreditation of the UKOU BEng (Hons) and integrated MEng are in process. The outcome of these will demonstrate just how far attitudes to distance learning have matured over the last forty years.

UKOU engineering students typically begin their Open University study in their late twenties, although many bring with them previous qualifications obtained part-time, such as Higher National Certificates and Diplomas. All but a very few are employed

full-time in engineering-related occupations, generally in senior technical or junior managerial posts at the start of their studies.

The UKOU describes its own style of distance learning as 'supported open learning', whereby students study independently and at a distance but with extensive learning support available essentially on demand. There is still heavy emphasis on print-based media, albeit increasingly provided online (almost all UKOU print materials are both sent to students and made available for downloading in e-book format). But the full gamut of alternative media is used across the range of modules a student is likely to study. Within the University and the global network of distance learning universities, there has always been considerable debate about the appropriate use of media for distance learners (Kirkwood and Joiner, 2003). This debate has more recently moved away from the media themselves towards the ways in which they can be deployed most effectively to develop the intended learning outcomes (Kirkwood and Price, 2005)."

The provision of residential 'summer' schools, for which the UKOU is renowned, has dwindled in recent years, mostly under pressure from students who find it increasingly problematical to take extended periods away from home or family during the summer months. The response of the University has been to make much more explicit links between module- or programme-level learning outcomes and specified residential or non-residential events requiring students' attendance. Students hoping to complete a BEng (Hons), for example, are now required to have satisfactorily completed two weeks of residential school activity and these are linked to the development of learning outcomes in the areas of working with other people and communication skills. The capstone postgraduate team project also requires students to attend two residential weekends, the first to form the teams and the second to present the results of their work.

The provision of home experiment kits has also decreased markedly across all areas of the University, but this is balanced to a large extent by the adoption of extensive computing activity in modelling, simulation and design.

Engineering study at the UKOU is characterized by:

- Introductory courses that adopt an issues-based approach, in order to demystify the subject and make it more attractive to students
- Resource-based approaches at higher levels, encouraging students to develop their understanding by exploring an issue in order to construct their own knowledge of the subject
- Team projects at a distance
- An emphasis on 'active learning'

(For examples see Bissell and Endean, 2007.)

Above all, the UKOU style is that of a learning conversation (Laurillard, 2002) whereby the isolated learner is constantly engaged in a dialogue with the 'teacher' through the particular learning medium they are using. What is more, engineering students are expected to draw on their own professional experience, particularly in the preparation of their assessment submissions and especially at postgraduate level.

5. Distance based approaches to the delivery of CDIO programmes

From the above it can be seen that the three distance education providers have (independently) developed substantial technology based learning resources to

support the off-campus delivery of their programmes and all have some (limited) face-to-face contact with their off-campus students. In this section we will discuss how this can be used to support CDIO and what further developments should be considered.

All universities (including Liverpool University) have facilitated team based activities through web based resources (Endean, 2007 and elsewhere at this conference; Brodie, 2006; Brodie, Aravinthan, Worden and Porter, 2006). In some cases this has included the conceive and design phases of the Initiative. Aspects of the implementation phase carried out individually have been facilitated using components of the home experiment kit (electronics) as well as in the form of software development, however the incorporation of design-implement and hands-on learning experiences could be better incorporated in the programme through the on-campus workshops. The operation phase is considered difficult to incorporate satisfactorily in any CDIO programme but can be facilitated through experiments (either on-campus or through the variety of distance based methods referred to earlier), through electronic links to real operations or through simulations (Crawley et al., 2007; Bissell and Endean, 2007).

Experiential active learning takes place when students take on roles that simulate engineering practice such as simulations and case studies. The Penfield Hospital project carried out by the University of Huddersfield is a virtual hospital that provides a web accessible database of real case studies for the training of health professionals. A less elaborate virtual business has been developed for the IT programs in the School of Engineering and Information Technology at Deakin University. A similar project based on a virtual engineering consultancy could be developed internationally to provide a data base of real engineering projects over a broad range of industries covering the four CDIO phases.

The EWB (Engineers without Borders) project being trialled this year at USQ also has potential, not only to be shared by a number of universities, but to include concepts of CDIO for both on-campus and distance students. EWB provides the outline of a number of projects which teams of students can participate in. The projects are usually carried out in remote communities or third world countries e.g. providing clean water supply; alternative cooking technology etc. Teams must investigate alternative solutions whilst being aware of the necessary cultural and resource constraints, and then creatively design a solution and evaluate it. It is strongly argued that part-time distance learners in full-time employment in authentic engineering environments are at a significant advantage over proximal full-time students in that they are daily exposed to experiences engineers encounter in their profession. They are, in fact, engineering practitioners as well as students. By drawing on their day-to-day activities and those of others in their surroundings, they are able to complete complex assessment tasks resulting in a deep understanding of the engineering principles that they are studying.

There are limitations, however. Few off-campus students have the opportunity in their workplace to acquire the full breadth of experience aimed at by CDIO, which engages students in the four phases of the product process or system lifecycle. One way of addressing this shortcoming, as well as providing an alternative for those not currently in engineering-related employment but aspiring to such, could be the inclusion of small industry case studies involving site visits to local companies during professional practice visits.

6. Discussion

There are aspects of distance education that provide advantages over proximal delivery. Current literature in engineering education lists required graduate attributes to include teamwork, problem solving and communication skills (ABET 2003; Engineering Council UK (EC UK) 2003). It suggests these attributes be expanded to include working globally in a multicultural environment; working in interdisciplinary, multi-skill teams; sharing of work tasks on a global and around the clock basis; working with digital communication tools and working in a virtual environment (National Academy of Engineering, 2004; Thoben K & Schwesig M, 2002). All of these attributes are embraced by CDIO and distance education is ideally placed to develop these attributes.

However practical team based activities are more difficult to implement for distance students. They may work on a project during an on-campus residential school, but these time frames do not allow time for large projects nor for student reflection on the learning that has happened. Nevertheless all four universities have successfully facilitated team based activities through web-based resources. For dual mode providers the linking of on-campus and distance design project teams through web and electronic communication media can enable each cohort to gain from a greater variety of skills and knowledge than would be available in either a distance only or proximal only team. Similarly linking teams internationally across institutions can provide distinct advantages such as developing skills in working globally in a multicultural environment, and enabling the pooling of project and delivery ideas and resources amongst the institutions.

However this only addresses the conceive and design aspects of CDIO. Options for the implement and operate phases for distance based students will require careful study and implementation. Options to consider include:

- Refocusing the on-campus professional practice workshops to address the implement and operate phases with the co-operation of industry partners close to the university;
- Developing geographically diverse industry partnerships to enable the distance based students to become involved in these activities closer to their home location;
- Include projects where distance students complete the detail design and on-campus team members build and test. The distance students would be involved in guiding the build phase and supporting the commissioning. Through team communication they all learn about each of the phases.

A major feature of CDIO is active and experiential learning. Much of the current level of experiential learning achieved by progressive distance education providers has been expensive not only for the provider in terms of developing specialised resources, but also for the student in time (loss of income) and travel in attending on-campus workshops. Increased use of technology based facilities would better facilitate the aims of CDIO and could be achieved more cost efficiently through inter-institutional sharing.

Staff development needed to provide the teaching skills for staff to become comfortable with the methodologies and pedagogic potential of active and co-operative learning in a distance based environment can be anticipated to be greater than that required for proximal students. However CDIO universities provide

considerable mutual support and sharing of ideas, there is currently limited distance education expertise in CDIO.

To address these issues we propose that a Distance Learning Special Interest Group be formed within CDIO to facilitate and support the development of CDIO programs by distance education, the sharing of ideas and specialised technology based resources; and co-operative research and development into new teaching innovations and resources.

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^{viii} Previously the Institution of Engineers, Australia

^{ix} The Australian Bachelor of Engineering degree (4 years) is the educational requirement for chartered membership of Engineers Australia and thus through the Washington Accord is recognised as the professional equivalent to the UK Master of Engineering (4 years).