IMPLEMENTATION OF PROJECT BASED LEARNING IN A LARGE ENGINEERING PROGRAMME

Gareth J. Bennett*, Kevin Kelly, Ruth Collins, Frank Boland, Ciaran McGoldrick, Sara Pavia, Kevin O'Kelly

Trinity College Dublin
Ireland

Abstract: The role of the engineer in industry has evolved, with today's engineering businesses seeking engineers with abilities and attributes in two broad areas - technical understanding and enabling skills. Institutions within the engineering community such as Engineers Ireland, the Accreditation Board for Engineering and Technology, the Royal Academy of Engineering and members of the CDIO (Conceive Design, Implement, Operate) initiative have highlighted a need for new approaches to learning and teaching of engineering within our academic institutions. This paper reports on the recent implementation of project based design courses in both of the two engineering programmes offered by Trinity College Dublin. The projects are each carried out in small groups (typically four to six) and are virtually free of podium based teaching. Initially, the students are provided with a design brief, foundation level technical input and raw materials. The projects are developed around the principles of CDIO which represents best international practice for teaching design. The implementation of this methodology requires self-directed learning, teamwork and small group learning, culminating in the actual building and testing of a prototype. Some projects finish with a public competition which tends to generate huge excitement. The new courses have been seen to foster innovation and to provide a format that channels the student's creative skills in a coherent and structured manner. The detail of the courses, the learning outcomes, and the resource overhead are presented as well as a discussion on the initial results from the programmes.
.

Keywords; Project Based Engineering, CDIO, Design.

**Correspondence to: School of Engineering, Museum Building, Trinity College Dublin, Dublin 2, Ireland. E-mail: gareth.bennett@tcd.ie*

1. INTRODUCTION

In the last ten years this country has seen dramatic changes to its engineering employment structure. With low "added value" manufacturing in Ireland no longer able to compete with lower wage costs in emerging economies, Irish Engineering must adapt in order to remain viable. The national strategy is to promote a Knowledge Economy. Irish Engineers must be able to "add value" to products, to be innovative and creative, to be customer and business focussed, to think globally and to work in multi-disciplinary teams with mature project management and communication skills.

A common paradigm of engineering third level education sees a first year syllabus which introduces basic engineering sciences and mathematics, proceeding in subsequent years through more applied science and discipline specific technologies, and culminating with a variety of ‘capstone’ courses and a substantial engineering project. In many cases the key engineering skills of synthesis, creativity, design and implementation are only really given full expression at this (late) stage.

1.1 CDIO Context

In early 2000 a group of four universities applied to the Knut and Alice Wallenberg Foundation of Sweden to fund a bold venture that would reshape engineering education in the USA and Europe. This new model, called CDIO (Conceive-Design-Implement-Operate) was to provide future generations of engineers with the knowledge, skills and attitudes required to assume leadership roles in the twenty first century. Since 2000 CDIO membership has spread across all continents with some 30 participating institutions. The stated goals of the CDIO initiative are to develop:

- A deep working knowledge of technical fundamentals.
- A refined ability to discover knowledge, solve problems, think about systems, and master other personal and professional attributes.
- An advanced ability to communicate and work in multidisciplinary teams.
- Skills to conceive, design, implement, and operate systems in an enterprise and societal context.

The CDIO belief is that graduating engineers should appreciate engineering processes, be able to contribute to the development of engineering products, and to do so while working in engineering organizations. The additional implicit expectation is that recent engineering graduates should be developing as whole, mature, and thoughtful individuals. Thus CDIO has the same goals as ABET and Engineers Ireland and so the publications of all three give much guidance on the methods whereby Irish teaching institutions may achieve the improvements to engineering education required by Engineers Ireland for our student base.

1.2 Benchmarking the degree programmes

The School of Engineering at Trinity College Dublin presently offers two four year engineering degree programmes: one leading to the degrees B.A., B.A.I. and the second the B.Sc. degree. Both are fully accredited by Engineers Ireland and by affiliated institutions such as I. Mech. E.

The B.A., B.A.I. degree has two cycles, Freshman (1^{st} & 2^{nd} years) and Sophister (3^{rd} & 4^{th} years). During the Freshman cycle, students study a common set of subjects. After successful completion of the Freshman cycle each student chooses a discipline from one of Civil, Mechanical, Electronic or Computer Engineering, or a combination of the latter two and follows specialist topics associated with their chosen stream over the next two years.

The B.Sc. degree differs from the B.A.I. degree in that the class size is smaller, there is a greater coverage of business and management topics, and the course is focussed on manufacturing engineering from entry level onwards. There is a significant overlap with the B.A.I. course in the Freshman cycle, with increasing specialisation in the sophister years. The small class size and the close control (the course is managed within one department rather than having to co-ordinate across the entire school), give the programme a high degree of agility with regard to implementing curriculum change.

The School of Engineering, TCD, has responded to requirements from new drivers such as: the Bologna process; a new set of industrial requirements and the change to a five year degree programme (B.A.I.-M.A.I.) by restructuring its freshman cycle to a more project oriented programme and by continuing to emphasise design in the B.Sc. degree. Previous works by Bennett 2008; Bennett et al. 2008; Kelly et al. 2008 and Lyons 2005 have discussed issues related to the implementation of CDIO compliant courses into engineering programmes. In each case, the dependence of success on a well designed group activity has been emphasised. Some detail of these and other initiatives is given in this paper.

2. INITIATIVES

2.1 Engineering Design I-Drawing and AutoCAD. B.A.I., 190 students, 1st Semester, Junior Freshman, 5ECTS.

This course contains fundamentals of design, ensuring that the students are equipped with the practical engineering drawing skills that will enable them to undertake design in engineering. On completion of the course, the students can understand and interpret technical drawings conforming design, and are capable of transforming spatial components and structures into drawings thus being able to disseminate accurate designs into a wide range of multidisciplinary professional audiences.

The course consists of two distinctive modules: drawing/graphics and Autocad. In the drawing/graphics module the students understand dimensioned projections and learn how to create two-dimensional images of objects using first and third angle orthographic projection as well as isometric, perspective and auxiliary projection. The students also interpret the meaning and intent of toleranced dimensions and geometric tolerance symbolism. In the Autocad module the students learn to inform and communicate elements of engineering by creating and delivering advanced graphics efficiently with the standard software Autocad.

2.1.2 Teaching Strategies

Lecture periods are interspersed with short tests wherein the student can evaluate their own understanding of the topic at that time. The students, in relatively small subsets of the overall class, undertake a number of formal drawing office sessions and computer laboratory practicals under the guidance of the lecturer and demonstrators. During this time further exercises are undertaken and guidance is available from both lecturers and demonstrators. Notes and quizzes are available to the student on the College website. In addition, a web tutorial guide is available to the students for self directed learning.

2.2 Engineering Design II-Project: Design, Build and Analyse a Roman Mangonel. B.A.I.: 190 and B.Sc.: 20 students. 2nd Semester, Junior Freshman, 10 ECTS.

In order to remain faithful to the CDIO philosophy, it is necessary that the students actually constructed something tangible which can be tested. The Mangonel (Roman catapult), as the core object of the programme, proves itself to be extremely well suited to being at the same time a mechanical device which can be designed, manufactured, analysed and operated and also the subject to which Civil and Electronic Engineering design assignments could be associated.

2.2.1 Syllabus

Groups of students will work together on assignments in the areas of Mechanical, Electronic and Civil Engineering. The assignments will facilitate the Design, Construction and Analysis of a Mangonel. In addition to some introductory lectures, the content of the students’ work during the year will consist of;

- the construction of a Mangonel: provided with Bill of Material (BOM), assembly instructions, parts and tools.
- the development of a software tool to allow the trajectory of a “missile” to be studied as a function of various operating parameters: launch velocity and angle, drag dependent terms.
- a structural analysis of certain key components of the Mangonel for static and dynamic stresses using values of material properties which are experimentally determined;
- the development of a micro-electronic system to allow the angular velocity of the throwing arm to be determined: infra red optical sensors, electronic components, e.g. PicAxe IC, JK Flip-Flops, NAND gates, software developed and uploaded to PICAXE see figure 1 for illustration.
- testing the Mangonel: functionality, distance, accuracy, spring balance to measure torque etc.
- student redesign of the throwing arm of the Mangonel to optimise for distance without compromising structural integrity;
- an inter-group competition at the end of the year: sponsorship from Honeycomb/Radionics etc. Irish Times Coverage (2008)

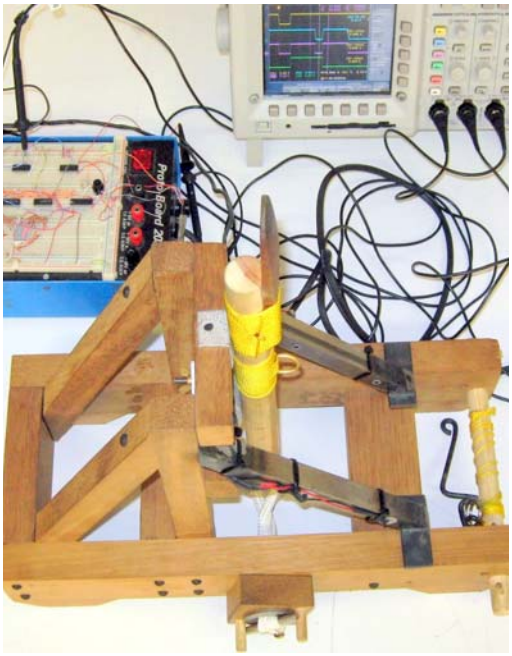

Figure 1. Mangonel with Electronic Circuitry

2.2.2 Teaching strategy and assessment modes

The course is delivered using a combination of introductory lectures and participation by the students in 15 “activities”. The activities are executed to support the syllabus of the course and might take place in specialized laboratories or on the rugby pitch. The course is structured using WebCT, where course material may be found and using which assignments are to be submitted. Students work in groups throughout the semester to encourage teamwork, cooperation and to avail of the different skills of its members. The students submit five individual assignments, two group based assignments, and two individual online multiple choice assessments.

2.3 Engineering Design III-Project: Design and Construction of a Refugee Shelter. B.A.I., 180 students, 1st Semester, Senior Freshman, 10 ECTS.

2.3.1 Syllabus

The class is divided into groups of approximately 9-10 students per group, to work on a project comprising an open ended design and build exercise that integrates civil and mechanical engineering. The first part of the project is to design a refugee shelter for an extreme climate with the following design requirements (see, for example, Figure 2):

- The shelter must be light-weight, portable and easy to erect and dismantle.
- The shelter must be designed for a 5 person capacity of their chosen demographic.
- The shelter must be able to store food above ground
- The shelter must have the ability to collect 70L of clean rain water per week, 20L of which must be stored in case of emergency
- The shelter must incorporate a solar cooker for meal preparation
- The shelter must adhere to all these requirements with a maximum cost of €100

The second part of the project incorporates the design of a solar cooker to boil one litre of water based on a solar flux of approximately 1kW/m^2. As the solar cooker is to be designed for developing countries, it had the further stipulation that it could not cost less than €10 and must be made from off-the-shelf components.

2.3.2 Teaching strategy and assessment modes

The course is delivered through a number of lectures and workshops throughout the semester. The students are provided with a wide range of multi-disciplinary lectures including the following: Project Management; Human Geography and Refugee Shelters; People Centred Design and Health and Safety; Sustainability and Recycling; Structures and Design; Solar Cooker and Heat Transfer. The lecture order is structured to encourage creativity and design thinking in the early weeks of the project.

There is no formal end-of-year examination for this subject, but all students must achieve an overall mark of at least 40% to pass. The overall mark is calculated using a combination of group and individual assignments. These assignments account for 60% and 40% of the overall mark, respectively. The group assignments include the following: group report on the interpretation of the design requirements; poster presentation; project management plan; construction and testing of the designs. The individual assignments include the following: structural hand calculations for the design of the refugee shelter; health and safety plan; sustainability and recycling plan; design of a solar cooker.

Figure 2 - Construction of ‘The Cardboard Cradle’, a design which incorporated recycled cardboard tubes from cardboard manufacturers

2.4 Engineering Design IV-Project: Design of Wireless, Autonomous Vehicle. B.A.I., 180 students, 2nd Semester, Senior Freshman, 10 ECTS.

In this design project students work in groups of about six and are required to design and implement a micro-simulation of a light rail system. The project has been developed this year as a sizable expansion of an earlier very successful design project which required the design, construction and test of line following vehicle. The primary deliverable of this expanded design project is for each group to create an autonomous vehicle, referred to as a buggy, that is under wireless supervisory control from a remote station, see Figure 3.

2.4.1 Syllabus

The objective of the project is to introduce the students to the engineering challenge of electronic and computer systems design. The project is an example of 'hardware and software co-design' and the scale of the task is such that it requires teamwork as a co-ordinated effort. Each group has access to a buggy, see Figure 4, a wireless communications module for the buggy, a wireless communications module for a PC and collective access to a test track that includes signalling gantries.

The tasks to be performed comprise i) overall management, final integration, testing and evaluation; ii) "buggy" design and engineering; iii) communications and control systems and infrastructure. Within each of these high-level design goals lie many individual tasks. Each group must identify and strategize for each of these tasks. The group leader(s) will manage and co-ordinate the overall project activities.

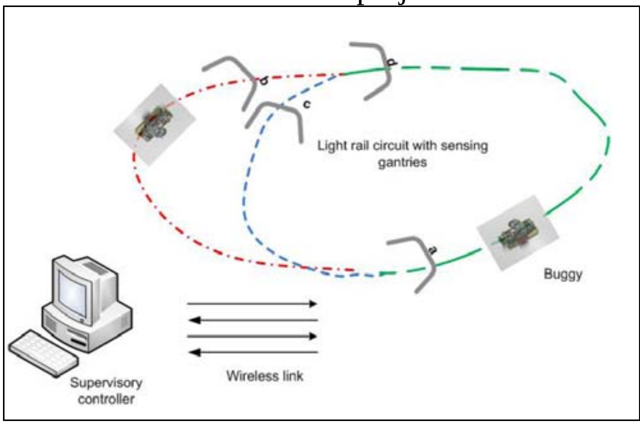

Figure 3. Engineering Design IV - System Overview

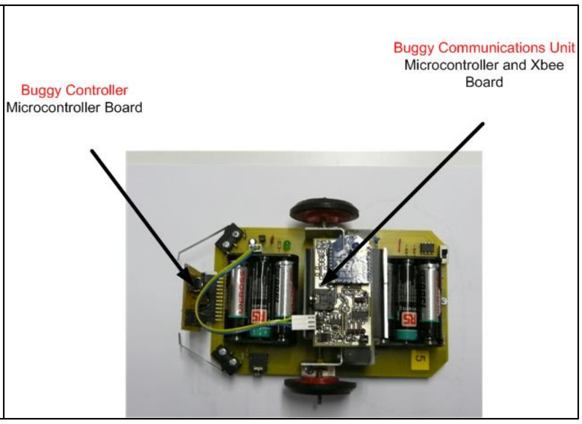

Figure 4. The Buggy and its subsystems

For the project to be a success requires each group to address the following sub-tasks:

Sub-Task1 : Buggy Controller -This task has to deliver the hardware and software (PicAxe) components of the buggy controller. The hardware configuration and behaviour must be agreed with the software developers for incorporation in the controller program. The design and construction of the system introduces electronic circuit testing and requires basic soldering skills.

Sub-Task 2: Communications and Supervisory Control – This task has to deliver the communications where XBee modules are to be used to establish wireless 2-way serial communications between the light-rail controller (PC) and the Buggies. The task also includes the development, implementation and validation of the supervisory control software and agreed communications protocol to run on a PC and on the buggy microcontroller Xbee board.

2.4.2 Teaching strategy and assessment modes

The project work is undertaken by the groups during weekly supervised and unsupervised timetabled sessions. In addition, there is a lecture programme which addresses selected topics relevant to the project and advisory sessions on group working and assessment briefings.

The project is assessed through interim submissions, a demonstration session and a collective final report. The breakdown of the assessment is -1. Interim submissions 30%. 2. Group Buggy demonstration, system inspection and oral assessment 40%, 3. Final Report 30%.

2.5 Engineering with Management Degree, B.Sc.: 20 students, four year programme.

Two areas were chosen to act as testbeds for new CDIO initiatives. These are described below, summarising the pre-existing practice, the new material and the results obtained.

2.5.1 Introduction to Manufacturing

This course had traditionally been podium-based, focussing on the technologies and basic theory, but leaving the relationship with design relatively unexplored. The implicit pedagogical strategy was to provide theory first (this course) and then re-inforce the theory with implementation examples (later design courses). It was decided to amend this strategy – ‘front-loading’ the course with design examples, providing theory as and when required, before returning in the latter part of the course to more traditional theory – with a ‘need’ for this knowledge hopefully having been identified by the student cohort, following their experience in the design based exercises. To this end, the students were randomly assigned to groups on their first day of college and charged with the task of making short presentations to the class. The purpose of this exercise was fourfold – to act as an ‘icebreaker’, to inculcate an ab-initio acceptance and understanding of the importance of groupwork and communication, to encourage students to approach the programme with a suitably enquiring frame of mind, and to prompt the students to consider everday objects from an engineering perspective and to identify technologies important to their manufacture. The subject matter of each groups presentation was to consider the design, manufacture and sale of an everyday object – e.g. a foldable chair, a bicycle wheel, an adjustable spanner etc. Some general feedback was given to the students, and they were asked to work, in groups, on the same task, for a longer presentation in the following weeks lecture. In between they were given information on materials selection methodology. Following the second presentation, the final part of the exercise involved each group taking on the (re-)design of another groups product.

2.5.2. Laboratory Programme

Several limitations were apparent with regard to the existing programme – notably that

- the scheduling requirements meant that the majority of the class were doing experiments a significantly long time either before or after they had learned the corresponding material (e.g. yield strength of materials) in class,
- the large class size (~200 students) meant that there was a significant boredom factor for the graduate students running the lab, as typically it had to be run 50 or so times per year. This was often readily apparent to the students who therefore had little ‘buy-in’ to what appeared to them to be a formulaic exercise.
- There was little or no opportunity for creativity on the part of the students in terms of how the experiment was conducted

Having taken the above limitations into account, it was decided to replace the above programme with one which consisted of 5 separate laboratory sessions, each of which made use of LEGO Mindstorms ™ kits. Mindstorms take the existing LEGO Technical range (which incorporates gears, motors, axles etc in addition to the 'standard' building blocks) and add a programmable control 'brick' and sensors (ultrasound, touch, sound and light). The programmable brick allows for bi-directional communication with a PC via USB or Bluetooth, either 'live' or periodically. The control brick has on-board RAM and is capable of storing programs and data which may be uploaded or downloaded to the PC. The software environment on the PC was developed by National Instruments and has much in common with their LabView™ suite.

The five labs were as follows:

- **Introduction** – the students were given instructions on how the software worked and given some simple tasks to do perform – involving construction and programming of a very basic robot.
- **Calibration Design** – the students were given information on calibration techniques and theory and asked to conceive and design an experiment to calibrate the ultrasound sensor for use as a distance measurement device. They were allowed to use any equipment or materials that they wished to source themselves. Feedback was given during the session on any ideas, from both the demonstrator and academic staff, and students were encouraged to physically implement ideas, where possible, on a trial basis.
- **Calibration Implementation** – the students were required to implement their experiment and to calibrate the sensor. A report template indicating the information required – broken down into boxes, each requiring a paragraph of text - was is given to each student.
- **Measurement Design** – the students were asked to design an experiment to measure the perimeter and surface area of a box. Further information was provided on the theory of experimental error. As with the 2nd laboratory, feedback on suggestions was given and active trials were are encouraged.
- **Measurement Implementation** – the students were required to implement the lab they had designed in the 4th session and to produce a report outlining their results, including inclusive of an error analysis. A list of required headings for the report was is given, but not to the level of structural detail that was provided in the 3rd lab.

3. RESULTS

The success of a newly introduced programme is always difficult to determine as by default there is no benchmark for comparison. In order to gather some structured feedback, anonymous student surveys which take place during the academic year are repeatedly organised. These are performed by the Centre for Academic Practise and Student Learning (CAPSL) and thus are completely independent of the School of Engineering. The survey questions cover all aspects of the course from organisation and evaluation to content. The results tend to be overwhelmingly positive with a typical breakdown of results given in Figure 5. Highly encouragingly, the students are motivated to go to the labs, find the material interesting, and the key goal, are stimulated to think critically about the subject matter. This latter point is one which differentiates the failures of podium based learning from a well structured project based course. In addition to the surveys, student "soundbites" from the students are extremely positive and find the project work, in the context of a week of mathematics and pure Engineering Science, to be more interesting and relevant to their career choice. High student numbers at the labs and a 100% turn out at the competitions are also indicative of enthusiastic participation.

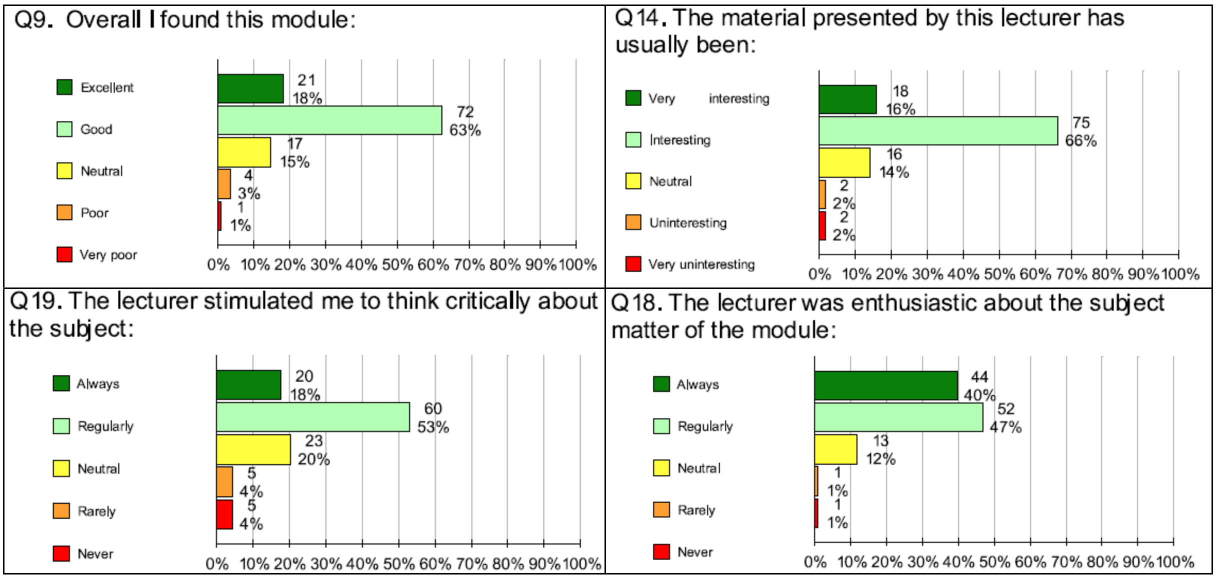

Figure 5. Sample of Results from Student Survey

To assess the new B.Sc. laboratory programme, the students were asked to fill in anonymous questionnaires where comparisons were made with other labs taken by the first year students. These are physics and chemistry for the majority, with several repeat students from the first cohort also having taken the pre-existing engineering labs. An analysis of the results indicates that greater satisfaction is reported for these LEGO labs than for any of the other labs in the programme, with the only positive scores for enjoyment and workload being reported for the LEGO labs. Interestingly, in terms of absolute time commitment, the LEGO labs are on a par with several of the other labs, but there appears to be a negative mental correlation between enjoyment and workload – i.e. students don't perceive the workload as onerous if they are having fun! This inference was reinforced on a practical level by the difficulty in getting the students to conclude experimenting with the LEGO at the conclusion of each session, so that the demonstrator could go home!

4. CONCLUSIONS

The structure of the B.A.I. and B.Sc. engineering degrees in Trinity College Dublin has recently been revised to a more project orientated curriculum. Whilst a strong focus on technical content remains in the syllabi, skills such as communication and teamwork are considered to be an integral part of education and should continue to be fostered. A description, three years after the introduction of the new project based courses, which are inspired by the CDIO methodology, is presented in this paper. The students, provided with only cursory technical fundamentals are encouraged to think critically on their subject matter and as a result address the solutions innovatively in a team work environment. The courses necessitate an initial investment in materials and time but this should decrease to maintenance levels with time. There will continue to be a requirement for a high number of demonstrator staff for the management of this course, however, the positive contribution of the course to the students' development is considered to warrant this expenditure.

5. ACKNOWLEGEMENTS

The authors would like to acknowledge their colleagues who contribute significantly to these courses: Bernadette Clerkin, Seán O'Callaghan, Garret O'Donnell, Mark Dyer, John

Fitzpatrick, Brian Foley, Bidisha Ghosh, Shane Hunt, Garry Lyons, Tony Robinson, Ciaran Simms, David Taylor, Roger West.

6. REFERENCES

Conceive Design Implement and Operate (CDIO) Standards:
Url:http://www.cdio.org/tools/cdio_standards.html.
ABET: Url:http://www.abet.org/index.shtml
Engineers Ireland: Url:http://www.iei.ie/
Bennett, G.J., 2008. To Design a Designer To Design Designs. In: P.P. Prendergast and C. Simms, eds. Perspectives on Design and Bioengineering. Trinity Centre for Bioengineering, 143-157.
Bennett, G.J., Lyons, G., and Kelly, K., 2008. Implementation of a CDIO compliant syllabus in a large engineering programme. *Proc. 25th International Manufacturing Conference*, Dublin Institute of Technology, Ireland. 3-5 September 2008.
Kelly, K., Lyons, G., Bennett, G.J., and Killeen, E., 2008. Further Experiences in CDIO Implentation'. *Proc. 25th International Manufacturing Conference*, Dublin Institute of Technology, Ireland. 3-5 September 2008.
Lyons C.G., 2005. Designing the Teaching of Engineering Design, *Proc. 22nd International Manufacturing Conference*, The Institute of Technology Tallaght, Dublin, Ireland. 31 August-2 September 2005.
The Irish Times 2008. Special report on Science, Engineering and Technology. *Taking a practical approach to very ancient weaponry*. Tuesday, 20 May 2008.