Renovating A Control Engineering Laboratory For Enhanced Learning

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Renovating A Control Engineering Laboratory For Enhanced Learning

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Renovating A Control Engineering Laboratory For Enhanced Learning

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Submitted to Cork Institute of Technology in partial fulfilment of the requirements for a Degree of Master of Engineering October 2009
Declaration

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of the institute or other institute of higher learning, except where due acknowledgment has been made in the text.

Signature of Author

Certified

Dr. T. Q. Munony

Date: 23/01/07
I wish to dedicate this work to my wife Louise. Thank you for your patience, and enduring a part time student for the last 12 years. This is the last of it I promise. (Well for a while anyway. 😊)
Abstract

In an attempt to both place the student at the centre of the learning process and thus improve student engagement with the discipline, and to incorporate professional skills into the engineering curriculum at the module level, an enquiry based learning (EBL) component to enhance teamwork, problem solving skills and the student's ability to learn independently was developed using current best practice in teaching and learning. As EBL is not widely used in engineering curricula in CIT, a pilot scale three week trial was performed during the academic year 2007-08 to evaluate the appropriateness of the pedagogy and student reactions to the change. The trial utilised a HP Inkjet Printer to provide an authentic, real world, problem, as the vehicle for enquiry and within this context student groups were asked to design and implement a control system for either the carriage or paper feed system.

The effectiveness of the intervention was initially evaluated through questionnaires and interviews. The results of the questionnaires and interviews indicated that students had very positive attitudes towards the intervention and were unanimous in their opinion that additional modules should adopt this approach. The student cohort perceived that their professional/transferable skills of teamwork, communication and information retrieval were especially enhanced by the EBL component. In general, students perceived that the printer apparatus was superior to traditional laboratory equipment as it was 'real-world' and closer to the discipline area. Upon completion of the module these students embarked on a six month work placement and were re-interviewed on return, to complete a cycle of skills development, industrial application and reflective evaluation. Again the main outcomes were that students believed that the selected skill set was relevant to an industrial setting and that the EBL component was effective in developing these skills.

In addition, this thesis presents a comprehensive evaluation of the Inkjet Printer apparatus as a vehicle for enquiry in control engineering. The evaluation may be viewed as a blueprint for designing an EBL control systems module, or alternatively decomposed to generate a series of laboratory sessions that range from the traditional
build/test to higher order identify/design/evaluate experiences. The learning resources utilised which are aligned with international best practice are detailed, the equipment used is inexpensive and globally available, and thus can be easily replicated internationally and tailored to suit local contexts.

To further enhance the student experience, a website providing simulation and remote experimentation using the printer, was designed and implemented, using the existing resources available within the Department.
Acknowledgements

Firstly, I would like to thank my supervisor Tom O'Mahony for agreeing to undertake this master's degree with me, for his patience and guidance during the last three years. Without his assistance and interest, I wouldn't have come this far.

To my family, Louise, Niamh, Aoife, and Maeve, thank you for understanding why I spent the time typing and not playing.

I would also like to thank my colleagues within the Department for the support that they have given my throughout the period of not only this masters, but also my undergraduate degree. In particular I would like to acknowledge the support given by my Heads of Department during my time of study; Mr. Paul Sliney, Ms. Irene Sheridan, and Dr. Joe Connell.

To Susan, Alan, and Neil, thanks for listening to my problems and the advice given.

I wish to acknowledge the support of Cork Institute of Technology and the Department of Electronic Engineering, who provided the funding for this research.
Publications


"The important thing is not to stop questioning. Curiosity has its own reason for existing."

Albert Einstein

"There is a great danger in the present day, lest science-teaching should degenerate into the accumulation of disconnected facts and unexplained formulae, which burden the memory without cultivating the understanding."

J. D. Everett (1873)
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Chapter 1: Introduction

1.1 Introduction

At the NSF/CSS workshop on New Directions in Control Engineering Education in 1998 there was a consensus on the importance of students being involved in control laboratory experiments as an essential part of control education, and that there was a need to "promote control systems laboratory development, especially the concept of shared laboratories, and make experimental projects an integral part of control education for all students, including graduate students" [1].

The Department Of Electronic Engineering at Cork Institute of Technology shares this consensus and practical laboratory sessions have been an important constituent of all courses since their inception in the 1970's. In the Control Engineering subjects the laboratory sessions were initially either simulation based or of a tutorial nature. In more recent years the emphasis has moved towards the student taking an active part in the experiment, using equipment of a standard nature including dc motors, liquid flow and level, twin tanks, and inverted pendulums. While laboratory programmes based on this equipment are extremely useful, the equipment is process based and suffers somewhat by being distanced from the real world of electronic engineering systems. It is left to the student's imagination to make the connection between the process involved in the experiment and the actual real world application that it is attempting to demonstrate. The laboratory sessions themselves are tutor focused, with students mostly replicating a procedure in order to finish the objective. These laboratories have not been project oriented and the assessment of an individual student is generally of a summative nature using only a laboratory report.

Up until the beginning of the new millennium the Honours Bachelor of Engineering Degree in Electronic Engineering attracted a large number of suitably academically qualified students and it was believed that the existing laboratory environment was adequate. However, with the bursting of the .COM bubble, electronic engineering at CIT has experienced declining interest, lower CAO points, and a shift towards less
mathematically proficient students. Such students experience difficulty with modules that have a strong mathematical background, such as the control systems modules.

Over the last decade there has been a shift in emphasis in the working environment, and in engineering practice, towards multidisciplinary teams of engineers, who are geographically dispersed across the globe, working on projects. These changes have not yet propagated, in general, into higher education, leading to both employers and accreditation bodies internationally, calling for engineering education reform, focusing primarily on issues related to the attitudes and skills required to prepare engineers for the profession, such as communication skills, teamwork, lifelong learning, and ethical responsibility.

It is within this context that this thesis presents an alternative pedagogy to create a more dynamic and ‘real’ experience for the student by modifying both the laboratory itself and laboratory sessions in a way that provides for enhanced learning within the control engineering elements of courses within the Department. The proposed component is student focused, and is structured in a manner to suit less mathematically proficient students. It is designed to help the student concretise the fundamental control engineering principles, while providing them with an opportunity to improve the skills and competencies advocated by national and professional bodies. This is achieved by using Enquiry Based Learning and combining best international practice from engineering education in a cooperative learning manner, using a HP inkjet printer which would be a familiar item to all students to provide an authentic ‘real world’ problem to solve.

1.2 Contribution of Thesis

Specifically the contributions of this thesis are to:

a. Evaluate the suitability of using a HP Inkjet Printer as a vehicle for enquiry.

b. Present a full pedagogical design of an EBL component in Control Engineering.
c. Complete a cycle of skills development, industrial application and reflective evaluation of the student experience of this learning model.

d. Develop a pedagogical tool based on a website comprising of simulation and remote experimentation using the printer.

1.3 Organisation of Thesis

The remainder of the thesis is organised as follows:

**Chapter 2** presents a brief history of engineering education, and describes the shift from a practical basis for engineering education towards a more theoretical one. Approaches to learning that can be used within engineering education to improve professional skills are described and in particular those that use Active Learning pedagogy. The impact of new technologies and globalisation on these pedagogies is mentioned.

**Chapter 3** develops the motivation for the EBL component and details the short trial performed during the academic year 2007-2008 focusing on the pedagogical resources used during the component, describes the students work during the component, and expounds upon the assessment strategy used during the component.

**Chapter 4** presents the tools used to evaluate the effectiveness of the trial. After completing the trial the student experience was evaluated using questionnaires and individual interviews. The results of these are presented and analysed. The chapter also presents the results of subsequent interviews, surveys undertaken after the students returned from industrial placement and after a final year module was completed.

**Chapter 5** presents a discussion on remote laboratories and the implementation of a website comprising of simulation and remote experimentation based on the printer.
**Chapter 6** This chapter looks to the future and considers the design of a thirteen week module delivered entirely through EBL. Its purpose is to establish that the suitability of the printer as a vehicle for enquiry over this extended time period and to examine the technical concepts that students are likely to discover.

**Chapter 7** draws conclusions from the results and arguments presented in the thesis, and suggests possible directions for future research.

**Appendix A** displays a step by step guide on the printer strip-down procedure.

**Appendix B** demonstrates implementation issues and lists the MATLAB ® script code used to develop the website.

**Appendix C** presents the forms used to gather survey information.
Chapter 2: Engineering Education

2.1 Engineering Education

The name "engineer" originated in the eleventh century from the Latin ingeniator, meaning one with ingenium, the ingenious one. The name, used for builders of ingenious fortifications or makers of ingenious devices, was closely related to the notion of ingenuity, which formed the original meaning of engine: an 'ingenious and useful device' until the word was taken over by steam engines and such [2]. Leonardo da Vinci bore the official title of Ingegnere Generale [3]. The first phase of modern engineering transpired during the Scientific Revolution in the late middle ages. Galileo's Two New Sciences [4], which seeks systematic explanations and adopts a scientific approach to practical problems, is a landmark and it is regarded by many engineering historians as the beginning of structural analysis, the mathematical representation and design of building structures [5]. This phase of engineering lasted through to the First Industrial Revolution, when machines, increasingly powered by steam engines, began to replace manpower in most areas of production [6].

Engineering as a profession emerged during the 19th century. Military engineering which focused on the construction of armaments, fortifications and infrastructure developed into civil engineering [7]. The French spearheaded civil engineering with emphasis on mathematics and began to develop university engineering education programmes under the sponsorship of their government [8]. In this regard, in 1794 they established the École Polytechnique [9]. Its function was to provide technically qualified officers, schooled in the use of systematic, analytical approaches to engineering problems, for the military and civil departments of the government. Other engineering schools were developed also and although practical training was included and industrial demands influenced the curriculum, the structure of these engineering schools remained as centres of theoretical training.
In northern Europe, engineering education developed two models of engineering recruitment and education [10]. The ‘fachhochschulen’ have their origins in the technical schools of the 19th century. These schools supplemented the skills of craftspersons by providing theoretical subjects to increase their knowledge and currently train people from an apprenticeship background. The ‘technische hochschulen’ is a more traditional university model involved with educating engineers directly from secondary schools [11].

In Britain a different institutional model emerged where engineering was seen as growing from practical, skilled crafts, and defined as a secondary trade, separate from the university structure [12]. The British, more empirically oriented, pioneered mechanical engineering and autonomous professional societies under the laissez-faire attitude of their government [13]. In the USA most colleges were of the British and fachhochschule model. They maintained a practical approach to engineering education with close ties to industry, and only a small number followed the more theoretical European model [14].

The onset of World War 2 led to a change in emphasis in engineering education and a move towards a more scientific base, due to the increase in public and military funding of engineering research. This promoted a move towards the French model and created both elite theoretical universities and technical schools of higher education across Europe and the USA [15]. Post war successes in the development of, for example, semiconductor electronic devices [16] and computing confirmed the superiority of the laboratory based environment in opening new technical frontiers over the practice based research and education models [17]. The emergence of the computer has led to new disciplines in engineering and to the use of computing based analytical tools to aid systems design for the engineer [18].

The creation of research universities as the model for engineering education has influenced the staffing of said institutions away from experienced practicing engineers towards engineers whose experience was more engineering science and laboratory based, and this has led to a more formal theoretical educational model
Even in the more technically oriented institutes of higher education the curriculum has been expanded to include more advanced mathematics and science and in recent years the author has found it difficult to differentiate between graduates of both educational models. This gradual shift in emphasis from the old traditional hands-on approach towards a more purely theoretical one is perhaps one of the main reasons that modern students are missing the, much valued by industry, transferable skills of teamwork, problem solving and communications. The opportunity to practice these skills by students has been diminished through the years as a result of the pedagogical changes that have taken place. In the following sections different approaches to learning and education, which could be used to redress the balance, will be explored.

2.2 Approaches to learning

2.2.1 Behaviourism

It is a commonly held view that education is the ‘filling of empty vessels’ [20], i.e. the process of imparting knowledge to those who lack it. This implies that the process requires nothing from the learner but a willingness to learn. This is a classical behaviourist approach to learning which stresses the importance of expectation and motivation within the learning process. Behaviourism [21], has its origins in the late nineteenth and early twentieth century when physiologists began investigating animals responses to stimuli such as the famous Pavlov’s’ Dog experiments [22]. Behaviourism has always acted at all levels of education, from the smile and clap of approval from a teacher in a baby infants class all the way to the placing of the hat upon the head of a PhD graduate student, albeit to different extents and in different ways. For instance adult learners (in this thesis, third level students will be classed as adult learners) require less behavioural control than young children.

---

1 The author provides technical support to a number of research areas within the Department of Electronic Engineering. The postgraduate population of these groups consists of students from a diverse range of higher education institutions both nationally and internationally. It is the authors experience that there is little in terms of ability to differentiate between them.
In the 1950's Benjamin Bloom developed his taxonomy of learning [23], which proposed three spheres of learning: the cognitive, affective and psychomotor, which convert the learning process into overt, observable behaviours, which are hierarchical according to complexity and sophistication.

![Figure 1. Blooms Cognitive Domain [24]](image)

The cognitive domain deals with the ways that internal knowledge is revealed by external behaviour, and it progresses from a demonstration of basic subject knowledge up to an ability to evaluate or judge the worth of knowledge. The levels in the cognitive domain are not sequential or fixed, and people may operate concurrently at different levels such as application and evaluation.

![Figure 2. Blooms Affective Domain [24]](image)

The affective domain deals with emotions, attitudes, values, etc. It deals with the relative importance placed upon what is learnt. Things that make sense and that can be used are valued; they are remembered and used again. But the things that are not valued are discarded. Krathwohl’s Affective Theory [23] talks about how systems are built based on learning and experience. This learning is a little more difficult to
measure. The measurement is mostly based on an individual’s belief and value system and on the individual’s actions.

![Diagram of Interaction between domains](image)

**Figure 3. Interaction between domains [24]**

There is an inter-relationship between the cognitive and affective domains of learning. If a value is placed on something, it is learned and used, and this helps to build the interaction between comprehension of something and its later application.

![Diagram of Blooms Psychomotor Domain](image)

**Figure 4. Blooms Psychomotor Domain [24]**

The psychomotor domain is the simplest domain but it is one which is significant in engineering education as it is skill based. If for instance the student must produce a product, this domain describes the practical instructional levels required in that task. In general there are two levels each for imitation, practice, and habit. Imitation is simply the ability to repeat a demonstration under the watchful eye of an instructor. The practice level is a proficiency building experience that may be conducted by the student on their own, without supervision. The habit level is reached when for instance the student can perform the skill reasonably well within a specific timeframe. The instruction is demonstration and proficiency building in nature.
Typically, student evaluations are performance or skill based. The content that is needed to perform the skill is cognitive and should be treated accordingly.

Behaviourism has influenced engineering education and resulted in a shift towards learning outcomes and a change in assessment procedures [25]. Learning outcomes are explicit statements of what a student should be able to do as a result of undertaking a particular course of study [26]. They help students to understand exactly what is expected of them and to tailor their learning activities accordingly. Effective assessment tasks should adequately test the performance of the metrics stated in the learning outcomes under the same conditions as those under which they are learned. For example if the learning outcome states that a student should be able to build and test an amplifier circuit using an op-amp then that is what should be assessed rather than describing the procedure in a written examination, which is often the case.

2.2.2 Cognitivism & Constructivism

Cognition refers to mental activity such as thinking, remembering, learning and using language. In cognitivism knowledge is viewed as symbolic, mental constructions in the mind of individuals, and as the outcome of learning [27]. Learning is a process, whereby recognition occurs through a series of continuous connections and repetition. Thus, learners begin to recognise new relations among the parts of a problem, and they reorganise the new information into understandable cognitive structures. Instruction is not a process that is imposed upon the learner but instead involves the learner, and empowers their internal mental processes. There are two main schools of cognitive learning psychology [28]: the Information Processing approach, which grew from work on artificial intelligence, which examines how information entering through the senses is encoded, stored, retrieved and utilised by the brain; and the Cognitive Constructivism approach that attempts to provide understanding of learning through accounts that relate the individual learner with their own internal cognitive structures. A major force in Cognitive Constructivism was Jean Piaget who began his career as a biologist, but became interested in the
nature of thought itself, especially in the development of thinking. He named this general area of research *genetic epistemology*, meaning the study of the development of knowledge. Of particular note is Piaget’s idea of assimilation and accommodation; which are the two complementary processes of adaptation or learning, through which awareness of the outside world is internalised [29]. Although one may predominate at any one moment, they are inseparable; assimilation is the process by which a person takes material into their mind from the environment, which may mean changing the evidence of their senses to make it fit. In accommodation, the internal world has to accommodate itself to the evidence with which it is confronted and thus adapt to it, which can be a more difficult and painful process.

Constructivism is a broad group of theories based on cognitivism, including trivial and social constructivism that explains knowledge acquisition and learning, and can be seen as a philosophy as well as a set of instructional practices. It suggests that although there is a real world out there, there is no meaning inherent in it. Thus, meaning is imposed by people and cultures [30]. Constructivism favours processes over end products; guided discovery instead of passive learning; authentic, real situations for learning over artificial ones; continuous assessments over multiple-choice exams, and so on. Trivial constructivism’s [31] basic premise is that knowledge is not received from outside, but by reflecting on previous experiences, and by fitting new information together with what is already known, new knowledge is constructed. In this way, mental models or ‘constructs’ are created from understanding, and when information is received, the new information has to be accommodated with the old. An important learning process occurs when these various constructs conflict, requiring all the constructs to be reconsidered and reconfigured, and this iterative and active process leads to deeper understanding and greater learning [31]. Social constructivism [32] maintains that the cultural and social context of the learning process is also paramount in that these shape the manner in which a learner perceives, interprets and attaches meaning to their experiences; knowledge is the result of social interaction and language use. Constructivist theory places the learner at the centre of the process and the learning process is also affected by the context and the beliefs and attitudes of the learner. It also places less emphasis
on the sequence of instruction and more emphasis on the design of the learning environment. Jonassen [33] summarizes what he refers to as "the implications of constructivism for instructional design". The following principles illustrate how knowledge construction can be facilitated:

1. Provide multiple representations of reality
2. Represent the natural complexity of the real world
3. Focus on knowledge construction, not reproduction
4. Present authentic tasks (contextualised rather than abstracted instruction)
5. Provide real-world, case-based learning environments, rather than pre-determined instructional sequences
6. Foster reflective practice
7. Enable context-and content dependent knowledge construction
8. Support collaborative construction of knowledge through social negotiation

Constructivism has benefits for engineering education in that it places the learner into situations where they become an active part in their own learning and places an emphasis on project and group work which of itself promotes generic skills in students.

2.2.3 Experiential Learning

Learning styles [34] can be defined as the way a particular individual approaches their own learning, and the way in which they process information. They characterize a person's typical manner of thinking, remembering or problem solving, and simply denote a tendency to behave in a certain manner. Experiential learning [35] occurs as a direct result of the learner's participation in events; it depends on the learner experiencing something and then reflecting on that experience. It is a learner centred approach which starts with the premise that people learn best from experience (learning-by-doing) [36]. It is particularly effective due to its holistic approach of addressing cognitive, emotional and the physical aspect of the learner.
One of the main proponents of learning styles is David A. Kolb who in his book “Experiential Learning, Experience as the Source of Learning and Development” [37] proposes a Theory of Experiential Learning in which he identifies four principal stages: Concrete Experiences (CE), Reflective Observation (RO), Abstract Conceptualization (AC), and Active Experimentation (AE).

Kolb defines learning as the process whereby knowledge is created through transformation of experience through the aforementioned four stages. According to Kolb, learning requires that individuals first should detect, depict, or grasp knowledge, and then a phase of construction should take place to complete the learning process. This construction is a transformation of the grasped knowledge into a mental model through experiencing this knowledge. Kolb proposed that the optimal learning would pass through a cycle of Concrete Experience, Reflective Observation, Abstract Conceptualization, and Active Experimentation. The learning cycle represents a method for reflecting on experience that is non-linear and can begin at any point on the cycle, but involvement of the four stages is important. The combination of the previous four stages is called the Kolb cycle of experiential learning and is shown schematically in Figure 5. The experiential learning model has been well accepted as an efficient pedagogical model of learning [38], and
experiential learning theory provides clear mechanisms for teaching and learning design, which are strongly aligned with the constructivist view on the way people construct their knowledge. Experiential learning theory emphasizes the role of experience in learning and the importance of developing links between classroom practices and the real world.

Within an engineering context Kolb’s ideas would place a great deal of importance on the use of laboratories and practical work to reinforce the theory presented to students. During the laboratory session, students are involved in the “Active Experimentation” stage of Kolb’s cycle, and because of the emphasis on doing the experiment, it also facilitates “Concrete Experience” and “Observation”. However, learning something from the experiment, or in other words, the transformation phase for constructing new knowledge through the experimentation, requires the information to be grasped or depicted.

2.2.4 Active Learning

Active learning has come to the fore as an effective approach to learning over the past several years and it is often presented as a radical change from traditional instruction. It is generally defined as an umbrella term that refers to several models of instruction that engage students in the learning process. In short, active learning requires students to do meaningful learning activities and think about what they are doing [39]. While this definition could include traditional activities such as homework, in practice active learning refers to activities that are introduced into the classroom. The core elements of active learning are student activity, engagement in the learning process, and subsequent reflection upon their learning. Active learning is often contrasted to the traditional lecture where students passively receive information from the instructor.

Whilst active learning can be carried out by individuals; it is more generally utilised within a group setting. Collaborative learning can refer to any instructional method in which students work together in small groups toward a common goal [40]. As such,
collaborative learning can be viewed as encompassing all group-based instructional methods, including cooperative learning [41], [42], [43]. The core element of collaborative learning is the emphasis on student interactions rather than on learning as a solitary activity. Cooperative learning can be defined as a structured form of group work where students work towards a common goal, while individual assessment is also present, [41], [44]. The most common model of cooperative learning found in the engineering literature is that of Johnson, Johnson and Smith [45], [46]. This model promotes five specific tenets, which are individual accountability, mutual interdependence, the use of interpersonal skills, face-to-face interaction, and self-assessment of team functioning. While different cooperative learning models exist [47], [48], the core element is a focus on cooperative incentives rather than competition to promote learning.

2.2.5 Enquiry Based Learning

Constructivism is a particular learning and teaching philosophy and Enquiry Based Learning (EBL) represents one possible realisation of this philosophy. EBL is an inductive teaching method [49] whereby students are presented with a challenge (such as a question to be answered, the interpretation of data, or the testing of a particular hypothesis) and then proceed to accomplish the desired learning by responding to that challenge. The instructor generally presents the required task and facilitates this process, but it is the students' responsibility to essentially project manage the process and pursue their own lines of enquiry. They seek evidence to support their ideas and take responsibility for analysing and presenting this appropriately, either as part of a group or as an individual supported by others, and by assuming these responsibilities for themselves students become equal partners in the learning process. EBL is usually organized around collaborative work in small groups or with structured support from others, thus promoting the social interaction and cohesion that can be difficult to achieve in a traditional system. Research into EBL suggests that it can improve the student experience, with enhanced recruitment, satisfaction and retention [49].
EBL offers flexibility to develop a range of abilities, including those required for lifelong learning. The modern economy places a premium on the ability to create knowledge, and on other key transferable skills such as leadership skills. These skills are required for the management of complex projects, and are particularly important in employment. Thus the use of open enquiries within EBL provides an effective mechanism for developing these skills [49].

Two subsets of enquiry based learning which are prevalent in engineering education are problem based learning and project based learning.

2.2.5.1 Problem Based Learning

Problem-based learning is an approach to learning made popular by Barrows and Tamblyn [50] at McMaster Medical School in Canada. This was because they found that students could learn content and skill but when faced with a patient they could not apply their knowledge in the practical situation. This approach marked a clear move away from problem-solving learning in which individual students answer a series of questions from information supplied by a lecturer. Problem based learning (PBL) is defined by Norman and Schmidt [51], as “a collection of carefully constructed problems that are presented to small groups of students who discuss the issues, identify from prior knowledge what is known and what is not known, and seek out information to solve the problem” (Fig.6). The goals of the PBL curriculum, as identified by Gallagher [52], are “to foster clinical-reasoning skills, problem-solving skills, or both, to enhance acquisition, retention, and use of knowledge, to improve students' self-directed learning skills, to develop students' intrinsic interest in the subject matter and, subsequently, their motivation to learn, and to facilitate the development of collaborative learning practices.” The literature suggests that students have almost universally benefited from the development of valuable generic skills such as problem solving, time and task management, group working, negotiating and communication skills as a consequence of the introduction of PBL [53].
Savin-Baden [54] describes seven modes of PBL implementation into the curriculum ranging from PBL on a shoestring to a fully integrated PBL curriculum and considers the importance of being able to implement it in a small experimental way to begin with, particularly in engineering faculties where staff invariably believe that 'teaching less' and facilitating learning appears irresponsible because they are not giving students considerable amounts of knowledge. It may not always be possible to move towards PBL within a curriculum but it is still possible to shift away from linear problems towards messy and complex problems that develop independence in inquiry and autonomy in students.

A number of educators argue that the traditional 'medical school' PBL approach is not particularly suited to the current undergraduate engineering higher education environment. For example, Allen et al. [55] note that students in the medical school setting have particular characteristics i.e. they are "intellectually mature and highly motivated" that only a subset of the typical engineering cohort would possess. In addition, they distinguish between the typical medical school environment which affords students the "opportunity to work in small groups with an assigned faculty tutor" and the engineering environment where such small student-tutor ratios are uncommon. Other authors have focused on the differing knowledge structures that
prevail in engineering and medicine. In medicine, knowledge is often classified as being encyclopaedic while engineering knowledge tends to be hierarchically structured [56], [57]. Thus the medical field is better suited to PBL while in engineering the order in which topics are studied can be crucial to developing students understanding. Designing a PBL process that facilitates this hierarchical structure is problematic. For students, it can be more difficult to engage in the PBL process if critical underlying knowledge e.g. mathematics, physics, electrical science, is missing or misconstrued. This issue is explored in [56] who furthermore note that the "findings from research on misconceptions suggest that PBL may not always lead to constructing the 'right' knowledge" which is a major disadvantage if this knowledge is to be subsequently relied upon in a professional context. Furthermore, a number of authors note that while PBL is closely aligned with medical practice it is not so closely aligned with engineering professional practice [56], [58]. Medical practice often requires problem solving skills where there will only be one solution that proves to be correct, and it will usually be arrived at relatively quickly. In contrast, engineering practice is typified by large-scale projects that persist for some time, which requires multidisciplinary teamwork, and requires a compromise between numbers of competing solutions. While it is accepted that inherent in this process is the requirement to solve problems, problem-solving in engineering requires the ability to reach a solution using data that is usually incomplete, whilst attempting to satisfy conflicting demands (from clients, technology, society) whilst minimising the impact on the environment and minimising the cost. Hence the traditional PBL approach may be insufficient for the acquisition of professional problem-solving skills in engineering due to the usual time scale of the problems and the range of activities that they include. While the movement towards implementing PBL is relatively new in the context of engineering education, it is a mature pedagogy and its effects are well researched. For instance Dochy et al. [59] have reviewed the literature from the 1990s concerned with evaluating the long-term effects of PBL. The main conclusion reiterates the assertion that the successful implementation of PBL has a considerable impact on the development of generic skills of students, and they do not acquire less knowledge compared to students educated in a traditional environment. Several studies come up with the same
findings: that there is no significant improvement in knowledge accrued, but significant improvement in skills development, see for example the recent studies by Faland and Frenay [60] and Crosthwaite et al. [61]. Furthermore, in the Schmidt and Moust [62] review of existing literature, they conclude that PBL seems to have a beneficial effect on long-term retention of knowledge such as remembering and understanding various concepts.

2.2.5.2 Project Based Learning

In contrast to PBL, project based learning (PjBL) has its roots in engineering and science faculties. Project-based learning is defined in various ways by different institutions and disciplines – nuances often depending on the extent of the project based learning (e.g. confined to a single course or spanning the curriculum) and the degree of student autonomy within the project [44], [45]. Most definitions include elements of cooperative work, prolonged active or experiential learning, and the development of key skills such as project management and the use of authentic projects [56]. In contrast to problem based learning, project based learning is usually directly supported by taught courses. In addition to these elements, many authors emphasise the meaningful use of technology as a learning aid [63]. In common with PBL, the project based learning experience begins with an end product or “artefact”. It is the desire to achieve this end product which drives the learning process and the instructor adopts the role of facilitator or advisor. Ideally, both the project and assessment are authentic and reflect professional practice. Both methodologies share a number of commonalities: they are constructivist pedagogies, both are student-focused; students work on authentic tasks; they use authentic assessment artefacts; they require collaborative learning; the lecturer becomes a facilitator. The difference, if any, is one of emphasis. In PjBL the emphasis is on producing a significant product, such as a final working model, a prototype, a simulation, etc, while in PBL the process is often more important than the actual product. As a consequence, PjBL tends to focus on the application of knowledge while in PBL the emphasis is on the construction of new knowledge.
During the 1970's a tradition of project pedagogy emerged (in parallel to PBL) in engineering education in Denmark and two new universities were founded: Roskilde University Centre and Aalborg University in order to create a new competence profile for engineers in response to demands from industry. These universities were influenced by the work of Berthelsen et al. [64], amongst others, who regarded project work as a mechanism for contributing to societal change, and implemented learning by doing and experiential learning strategies to facilitate this change. In [64] five central principles of project based pedagogies are identified: problem orientation, project organisation, interdisciplinary considerations, participant control, and the exemplary function. These core principles define a process where a concrete problem needs to be addressed via a complex effort using a multidisciplinary team, where the onus is on the team members themselves to make decisions and manage the project. The exemplary principle ensures that students learn not just isolated elements but have to link theory and practice. Project based learning has defined the curriculum in engineering, science and humanities at Aalborg, and it has perhaps become the exemplar for PjBL in engineering education.

This leads to the question of which methodology is most suitable for engineering education, and from an engineering perspective, the significant advantage of PjBL is that it closely mirrors the professional behaviour of an engineer and provides the engineering student with opportunities to develop and practice key skills such as project management and time management [58], while at the same time allows the student to experience complex, open-ended projects, that may persist for a significant length of time and require extended teamwork, where members adopt clearly defined roles/tasks. As the PjBL environment is usually supported by some taught courses, these more traditional elements can facilitate the hierarchical knowledge structure that dominates much of engineering education and this approach facilitates many engineering faculties as it allows a mix of teaching styles where the more conservative staff members can deliver the taught courses while the more progressive staff can deliver the project-based elements.
2.3 Institutional Implementations of EBL

While in its purest form, project based learning may be suited best for engineering education. The reality is that most implementations contain a blend of both projects and problems and in practice it can be difficult to distinguish between the two. Consequently, in the following the distinction is disregarded and the term EBL is applied to encompass both.

A number of institutions globally have implemented forms of EBL as their primary pedagogical technique for teaching the curriculum across a range of disciplines. These include Franklin W. Olin College of Engineering in Boston, USA who since 2002 have implemented active learning across the campus [65]. In engineering, EBL is introduced in first year and the curriculum is built around actual design and construction projects. The final year project occupies about half of the year, allowing students to work as real engineers, providing a solution to a real engineering project. Olin encourages group learning activities and small class sizes with a strong focus on areas of study outside the exact sciences including entrepreneurship, arts, humanities, and social sciences. Harvey Mudd College (HMC) in the USA has implemented an 'Engineering Clinic' approach since 1965 in which students work on real, external sponsored design and development projects. In a similar manner to the "clinical" experience at medical school where students learn the practice of their profession by working with real patients and real problems, in the Engineering Clinic students are exposed to professional engineering practice by working on real problems for real clients. Students work in project teams consisting of a mix of both junior and senior students. They work on professional design and development projects for clients from government, industry, and the community [66]. HMC's engineering curriculum is unusual in that it offers only a single, broad, unspecialized degree in engineering [67]. This means that the projects in the engineering clinic can be truly multidisciplinary without the restriction of specializations. The University of Delaware hosts the largest-scale implementation of EBL within undergraduate courses in the United States, where it is used in many courses, from mathematics to physics [68]. At McMaster University the original medical school home of PBL, it
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has been implemented in the chemical engineering program, where EBL is used as
part of two courses: one topic in a junior-level course; and five topics in a senior-
level course [69]. Maastricht University in the Netherlands opened its doors in 1976
as a medical school teaching though EBL and since has introduced EBL across the
whole campus. Maastricht's engineering programme is designed around a Project-
Centred Learning model, in which students work closely together in teams on real-
life knowledge problems, often provided by external companies [70]. In September
2001, EBL was introduced as the primary teaching method for undergraduate
engineering programmes at the University of Manchester [71]. Other universities in
the UK that widely use EBL in engineering courses include Coventry University,
Imperial College, University of London and University of Strathclyde [72].

A recent international consortium is the Conceive, Design, Implement, Operate
(CDIO) initiative, originally devised by Chalmers University of Technology, the
Royal Institute of Technology, Linköping University (all in Sweden) and
Massachusetts Institute of Technology in the USA. The consortium proposes a
change in engineering education stressing engineering fundamentals, set in the
context of the Conceiving — Designing — Implementing — Operating processes,
which engineers use to create systems and products. The CDIO Initiative places a
heavy emphasis on student projects complemented by industrial internships. It
promotes the use of active group learning experiences, both within the classroom
environment and also within modern learning workshops and laboratories. It also
promotes the need for rigorous assessment and evaluation processes [73].
Internationally a number of electronic engineering programmes have been
implemented within a traditionally taught curriculum using an active learning
pedagogy, from a EBL based course in analogue electronics in Chitkara Institute of
Engineering and Technology (CIET), Punjab, India [74], to a digital systems EBL
course used from second year through to fourth year at the Department of Electrical
and Computer Engineering at James Cook University, Australia [75]. At RWTH
Aachen University in Germany embedded programming is being taught to third and
fourth year students using an active learning project based approach [76]. At the
Universiti Teknologi Malaysia, a fourth year module in process dynamics and
control has been implemented using EBL since 2004 [77]. The Mechanical and Manufacturing and the Electronic Engineering schools at Dublin City University offer an EBL module for all first year Engineering Students [78].

2.4 Why is EBL not implemented universally?

If using an active learning pedagogy such as EBL is the great panacea for the ills of the traditional engineering curriculum then it should be in place in the majority of teaching institutions at this time, but this is plainly not the case. To traditional teaching staff, particularly in engineering faculties, active learning is seen to absorb the valuable extra time needed to ‘cover the curriculum’ and many have reservations regarding the perceived unfairness of group learning and the difficulties associated with assessing group learning [79]. Some evidence for this can be gleaned from a recent presentation at Penn State [80], in which Richard Felder (an advocate for cooperative learning in engineering education since the 1970’s) is still trying to convince lecturing staff of the advantages of using active learning within the curriculum. Within the literature, EBL is not without its opponents who argue that it is costly and ineffective because it requires more of students and instructor’s time to obtain similar learning outcomes [81]. Kirschner, Sweller, and Clark [82] propose that PBL is less effective than traditional methods because its approach of providing minimum guidance is not compatible with human cognitive architecture. The authors’ arguments however ignore the role of the instructor as a facilitator within the EBL process. Several meta-analyses on empirical studies of PBL were conducted in the past ([60], [83], [84], [85], [86], [87]), and the findings of these meta-analyses regarding the effectiveness of PBL were mixed. The findings indicated that PBL was superior when it comes to long-term retention, skill development and satisfaction of students and teachers, while traditional approaches were more effective for short-term retention as measured by standardized board exams [88]. It must be stated that these meta-analyses dealt mainly with medicine and Prince [89] notes that there is very little empirical data available for PBL’s effectiveness with undergraduate engineering programs. Recently however, the main motivation for using active learning pedagogies is to promote generic skills. This is largely driven by the
requirements of employers, with change being advocated and imposed by statutory and accreditation bodies. In the engineering literature, there are a number of documented attempts to explicitly target the professional skills required by industry using active learning. These range from entering students into an international robot competition [90] to using direct collaboration with industry within the classroom [91]. These approaches try to provide real world authentic problems organised in a way to mimic professional practice. Fink in particular demonstrates the effectiveness of using real world problems as a good way of initiating and maintaining communication between academia and industry [92].

2.5 EBL & Assessment.

Assessment makes a profound impact on the ethos of a programme. There needs to be an alignment between the manner of assessment and the format of the EBL strategy used within a course, which is able to accurately and fairly assess both the ‘hard’ and ‘soft’ skills achieved by the student. This principle of constructive alignment was presented by Biggs [93], and its principles recognise the importance of aligning learning outcomes, teaching and learning activities, and assessment tasks, particularly when the intention is to encourage deep, rather than surface approaches to learning. It represents a holistic approach to analysing and developing the curriculum. It is not possible to change one element without rethinking the whole. Good assessment strategies develop individuals who are highly capable and are motivated to continue to develop their professional abilities, whereas bad assessment strategies can be seen as a series of examinations that are to be passed one after another, and just passing the exam becomes the purpose of learning. Implementing PBL necessitates adequate planning as to the methods of assessment that will be utilised as Gibbs [94] emphasises the fact that assessment systems are the most powerful factor influencing a students learning process and that they can be used strategically to enhance student learning outcomes; thus assessment activities need to be designed that reflect all of the desired learning outcomes of a particular course. Kolmos and Holgaard [95] discuss the use of both formative assessment (which is used to give timely feedback to the student), and summative assessment (which is
used in effect to grade the student overall). They propose that both types of assessment should be carefully constructed to support the students learning which should be focused on both learning and performance, using a mix of assessment methods. This paper also describes the use of group based versus individual summative assessment at Aalborg and comments on the inability of the individual exam to test knowledge and skills to the same level as a group exam.

Within engineering there is usually a clear definition of the ‘hard’ skills that are to be assessed as there is a well understood and clearly defined body of knowledge used in a particular discipline that is broadly accepted across the engineering education community. Assessment of the various learning outcomes can be largely limited to the coursework that a student has undertaken, and is unambiguous. However the various accreditation bodies now have learning outcomes pertaining to the ‘soft’ professional skills and there are few robust, effective measures of the scale to which those outcomes are being met by students. For instance assessing a students “ability to work effectively as an individual, in teams, and in multi-disciplinary settings together with the capacity to undertake lifelong learning” [96] could potentially be quite a perilous affair as meeting this outcome would be most likely the culmination of several courses involving teamwork, exposure to teamwork outside the classroom including cooperative placement, and a longitudinal study of a students ability to self-learn. So to properly assess this outcome for any student necessitates assessing all such sources, and this may or may not be possible within a certain timeframe. An attempt to enable this is demonstrated by McGourty [97] who uses multisource feedback, where critical information on a student’s competencies and behaviours are collated from several sources including peer and self assessments along with instructor evaluations. The resulting formative assessment data is presented to a student who can then reflect on the metrics being assessed and make decisions on any actions that are required to be taken. This type of multifaceted approach has been shown by McGourty [97] to promote consistent student improvement according to the perceptions of peers and faculty. To adequately assess both ‘hard’ and ‘soft’ skills within a PBL framework requires careful and thoughtful planning. It is necessary to produce learning outcomes that can be adequately addressed by the
student and assessed accurately and fairly using both formative and summative strategies. New assessment criteria are needed to test a student's ability to analyse and solve complex problems e.g. criteria for problem solving methods or for teamwork. A variety of assessment methods are needed to ensure that good performance is rewarded perhaps consisting of oral and written elements, peer and self assessments and, in keeping with behaviourist ideals, providing for authentic assessment of professional skills. Some thought needs to be given to the use of group assessment vis-a-vis individual assessment; while group assessment is the most suitable for testing the objectives of problem based, interdisciplinary and cooperative learning [98], care must be taken to ensure that 'individual accountability' is present within any group work as individual assessment acts as a motivating factor and also acts as an impediment to 'hitchhikers' skating along on the back of other group members work. A student's individual score should accurately reflect both their technical ability and their professional skillset.

2.6 ICT and EBL.

When Information and Communications Technology (ICT) is used in the existing education process, it often merely replaces former manually or mechanically performed activities that improve the quality and efficiency of educational processes, e.g. the use of a data projector instead of an overhead projector. There now exists a 'playstation generation' student body that are computer literate from a young age, are comfortable in, and expect to operate within a technologically advanced multimedia society.

An assessment study by Light [99] of Harvard students strongly suggests that one of the crucial factors in the educational development of the undergraduate is the "degree to which the student is actively engaged or involved in the undergraduate experience". Student engagement in the light of this technological cultural change will require that faculty staff begin to implement new technologies into the curriculum. Engineering is in a relatively good position in this regard as the use of computers as tools for modelling, CAD, and simulation, for example, is prevalent and students would be familiar with using them within an engineering context;
indeed even the most un-technological staff member cannot at this stage avoid some use of computers.

However the use of ICT is not restricted to merely using a PC as an engineering tool. In an age of instant communication, the internet as an enabler of that communication has greatly shrunk the globe. Web 2.0 [100] and eLearning [101] have moved the medium of teaching from the classroom to the virtual environment in some cases and EBL has to evolve in order to be appropriately used in that arena. In his talk to faculty at Penn State [80], Felder comments on the threat of online universities to the traditional university because of the manner in which they engage with students. Their use of multimedia and cooperative learning strategies make them more attractive to modern students. Learning is on the move through the use of tools such as blogs and wikis, podcasts, and m-learning, which have a huge and interesting pedagogical potential [102], and PBL will have to embrace these technologies in order to get the student to engage with the process, which will in turn provide the requisite learning outcomes.

Savin-Baden [103] presents two potential shifts in the way PBL may be carried out in the future. She defines problem-based learning online (PBLonline) as “students working in teams of four to six on a series of problem scenarios that combine to make up a module or unit that may then form a programme.” They are expected to work collaboratively to both manage and solve the problem. Students work in real-time or asynchronously, but what is important is that they work together. Tools such as Chat, Shared Whiteboards, Video conferencing and Group browsing are central to ensuring collaboration within the problem-based learning team. Groups may work at a distance or on campus, but they will begin by working out what they need to learn to engage with the problem situation. This may take place through a shared whiteboard, conferring or an email discussion group. What is also important is that students have access both to the objectives of the module and the ability to negotiate their own learning needs in the context of the given outcomes. Facilitation occurs through the lecturer having access to the ongoing discussions without necessarily participating in them. Tutors also plan real-time sessions with the PBLonline team in
order to engage with the discussion and facilitate the learning. However she questions the value of real-time PBLonline for students undertaking the same programme at the same university, unless it is used because of long distances between campus sites where students are using the same problem-based learning scenario. There also needs to be questions asked about whether having asynchronous teams adds something different to PBLonline. However in a shrinking world, and in distance education, across time zones and campus sites, this would be useful and suit different students' lives and working practices. Savin-Baden [103] also discusses learning in the context of immersive virtual worlds such as Second Life [104] and computer based simulations. Most research to date has been undertaken into students' experiences of virtual learning environments, discussion forums and perspectives about what and how online learning has been implemented. Practising skills within a virtual environment online offers advantages over learning through real-life practice, in particular the exposure of learners to a wide range of scenarios (more than they are likely to meet in a standard face-to-face programme) at a time and pace convenient to the learner, together with consistent feedback. It offers learners the chance to make mistakes without real-world repercussions. Savin-Baden et al. [105] describe the PREVIEW project, which is an example of a project that is investigating, implementing, and evaluating a user-focused approach to developing scenarios and materials, and linking the emerging technologies of virtual worlds with interactive PBL online, to create immersive collaborative tutorials.

Hadgraft [106] calls for the sharing of PBL resources in a global context, where existing good online materials are identified and made readily available to students and staff. Good online assessment schemes need to be developed so that students can test their skills at any time, without waiting for end of semester exams. This process is currently being undertaken at the University of Melbourne where they are beginning to assemble suitable online tutorials with robust online assessment. He proposes a mainly project based learning system which would be backed up by a "knowledge management system", where both students and staff would contribute to improving the available learning resources. A current example is the use of a wiki
where students contribute to the improvement of the lecture materials as well as contribute their own research papers as lecture extensions [107].

It is through the use of ubiquitous ICT tools that are familiar to students that PBL will be enriched and will move forward. The ability to implement these technologies reasonably easily will enable collaboration between members of a team that could be diverse in terms of geography and discipline, and also facilitate the beginning of a global PBL learning community where resources and ideas are shared.

2.7 The Impact of Globalisation

As more engineers are produced in developing countries, many technological skills will simply become commodities, meaning that as technological skills and knowledge becomes standardised, they will be treated like any other commodity that is traded in an international marketplace [108]. It makes no difference if an engineering design is produced in Australia, India or Mexico. It is expected that the effective operation of this ‘engineering skills marketplace’ will drive down the relative value of technical expertise, and so in the future lead to lower relative salaries for engineers with purely technical skills, as much of this work is outsourced to India and China [109]. Of the 2,800,000 degrees in engineering and/or science awarded worldwide in 2004, 1,200,000 were awarded in Asian universities, 830,000 in Europe and 400,000 in the USA [110]. Both India and China are becoming global industrial powerhouses and there is a gradual shift towards Asia as being the global technological hub instead of Western Europe/America. This move has also changed the way that businesses operate in a global marketplace, with engineers from all over the world operating from geographically separate areas working on part or all of an engineering project due to new ICT which enable instant communications. Swearengen et al. [111], concerned with outsourcing capturing an increasing percentage of engineering work, suggest “that engineers will become “free agents” in a professional services market”. In order to thrive engineers will have to “be able to work productively with radically different cultures, educational backgrounds, technical standards, quality standards, professional registration requirements, and
time zones. An engineer must not only master the elements of global design, manufacture, marketing, and distribution, but also prepare to participate as a contractor in a twenty-four-hour virtual enterprise” [111].

It must be illustrated to students that in a global context, engineering solutions, whether consumer products or unintended consequences such as resource exhaustion and environmental pollution, increasingly cross or transcend international boundaries, and that for example, global sustainability may eventually outweigh technical and other aspects of engineering. Students must have a greater understanding of contemporary issues as well as engineering solutions in a global and social context.

In the face of this change it needs to be asked what it is engineering students need to learn and how should it be taught? Are the traditional methods of engineering education capable of providing graduates who can operate effectively in such a world, and able to reflect the main changes in engineering practice: the kinds of tasks that engineers will do, the global context in which they operate, and the teamwork skills required of engineers working with a “global team”? To provide an authentic global view in a local setting is not an easy proposition. Shuman et al. [112] provide a review of a number of universities who have put in place highly innovative educational programmes to introduce issues related to globalisation, sustainability, and development, especially in lesser developed countries, and have in place international agreements to allow their students gain international experience. Worchester Polytechnic Institute (WPI) is one of the leaders in enabling its students to study engineering within a global and social context [113]. WPI’s program uses a “Major Qualifying Project—the equivalent of a nine-credit capstone design experience and provides a professional level application of the students’ knowledge in their major fields. It typically involves the design, synthesis, and realization of a solution to a real-world technical problem” [113]. WPI has set up a number of project centres, including ones in Europe, Africa, and the Far East. Colorado School of Mines (CSM) has introduced a programme with a focus on “humanitarian engineering.” Their goal is to nurture a cadre of engineers that is sensitive to social
contexts and committed and qualified to serve humanity by contributing to the solution of complex problems at regional, national, and international levels and locations around the world. This goal is to be achieved through the development of a humanitarian component for the CSM engineering curriculum that will teach engineering students how to bring technical knowledge and skill, as well as cultural sensitivity, to bear on the real-world problems of the less materially advantaged [114]. Hadgraft and Smith [115] propose an entire civil engineering curriculum based entirely on an EBL approach using complex technical situations within complex social, environmental and economic conditions. The future of engineering education may indeed be one where educational institutions operate on a global level, and where resources and knowledge are shared. These institutions will perhaps facilitate students to use active learning methodologies, while interacting with team members who are based on different continents using instant communications. This scenario provides for students all working together in a multidisciplinary team, on real sustainable projects in partnership with industry and other stakeholders.

2.8 Summary

Changes in both the working environment for professional engineers, and the attributes of students entering higher education, have prompted calls from accreditation bodies both nationally and internationally, for academia to promote and provide professional skills such as problem solving, team working, and lifelong learning. However these bodies have not suggested suitable mechanisms to achieve this change and it is left to the individual institutions to implement a process to achieve these aims. Active learning approaches including Enquiry Based Learning (EBL) provide faculty members with a methodology that allows students develop the requisite professional skill-sets, and research has shown that use of these methods does not diminish knowledge accrued in comparison with traditional methods of learning, and indeed provides a significant improvement in skills development.

The effects of globalisation and modern communications technologies are not to be underestimated. The expectations of a technologically ‘savvy’ student body requires
the use of new technologies such as blogs, wikis, and m-learning to be integrated into
the curriculum, in order to provide an element of student engagement, and EBL provides a suitable vehicle for their introduction.

It is perhaps by blending the various elements that have been discussed and “cutting your cloth to suit your measure” that will allow the more progressive members of faculty to push forward with the curricular change necessary to prepare students for the changing work environment, as PBL in all its forms has the potential to act as an enabler for engineering educators to address the issues of changed student competencies, the promotion of professional skills and the awareness that increasing globalisation is bringing. Even its introduction on a small scale, perhaps within one or two modules, can have a positive effect on student engagement, and illustrate to faculty the advantages of using active learning pedagogies within engineering education. The next chapter presents an EBL component that was designed to address some of these issues within a control systems module at the Department of Electronic Engineering at CIT.
Chapter 3: Designing an EBL Module

3.1 Motivation for Change

The Department of Electronic Engineering at Cork Institute of Technology offers qualifications from level 6 to level 10 of the National Framework of Qualifications in Electronic Engineering. The Department offers a four-year level 8 Honours Bachelor of Engineering in Electronic Engineering programme. Within this programme the module control systems is offered as a mandatory module in year three. Students taking this module typically have studied Laplace, Fourier and Z-Transforms in a mathematics course and have previous, albeit limited, exposure to basic linear systems concepts. The course content includes open and closed-loop systems, block diagram algebra, system dynamics, performance and stability, frequency responses, root-locus, sampling, and the analysis of sampled-data systems. The module was timetabled at five hours per week, three of which were lecture based and these lectures were supported by a two hour laboratory. The objective of the two-hour laboratory was to provide students with opportunities to develop their understanding of the core concepts through simulation exercises using MATLAB® and Simulink® [116].

In the past this course structure worked quite well as the programme attracted a large number of suitably qualified students. But in more recent times, science and engineering programmes have experienced a decline in student numbers in Ireland and electronic engineering has been especially affected by the burst of the .COM bubble. Interest has largely evaporated and as a consequence the CAO entry points for the program have plummeted and the program now accepts all suitably qualified applicants. An effect of this policy is that the program currently admits students with arguably lower mathematical ability than would have been the case ten years ago. This difference is particularly noticeable in modules that have a strong mathematical background, such as the control systems modules. Over time, it was noted that increasingly greater resources were being devoted to teaching students basic
(engineering) mathematical techniques, that students inability to comfortably handle these techniques meant that they focused a great deal of attention on these techniques and often missed the core concept of the lesson and became increasingly demotivated by the module - often viewing it as an additional maths module.

To address this problem the module was transformed from its traditional lecture plus laboratory format to a studio based course where theory and practice were delivered simultaneously and in a just-in-time fashion. Furthermore, the use of MATLAB® was extended and became embedded into the module. This enabled students to avoid performing protracted mathematical operations by hand and transferred this burden to the computer. In accordance with Biggs' constructive alignment philosophy [93] the assessment was also changed and the terminal exam became an open-book computer assisted exam that used the same CAD software. Upon reflection it was evident that this transformation was successful in that student attitudes were more positive towards the course and that through integrating the CAD tools the emphasis changed from the underlying mathematics to the core principles and concepts of the discipline, and course evaluations supported these observations.

In 2006 Engineers Ireland [96] reviewed the electronic engineering programme and while the review panel were very satisfied that the programme achieved the majority of the specified programme outcomes, they were critical of our students' ability to identify the initial problem in the problem solving process. Following the review the Department decided to address the issue at the module level by encouraging individual lecturers to introduce authentic, open problems into their modules. Subsequent to that review, a promotional video for the Department was produced aimed at informing prospective students what electronic engineering is and what the Department had to offer. The video included a snippet of third year students in the control systems laboratory performing some practical work and the students were subsequently interviewed on their experience of the programme, motivation for choosing electronic engineering and CIT, and the specific subject matter that was

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2 Based on oral feedback from students.
3 At the time, the lecturer did not deem these critically important and so were not retained. Results were not published.
recorded. During the interview most of the students were asked to give an example of where control engineering is used and it was surprising to see the difficulty that the students experienced in answering this question. None of the students were able to give examples related to electronic engineering, despite numerous examples being used in course notes, and most tried to relate to the physical equipment used in the laboratory - control of liquid level, temperature, pH, etc. It seemed that students were unable to contextualise and internalise their learning.

Engineering education reform has added to these local issues. In Ireland this has been driven by national accreditation bodies who have demanded a move towards a student-centred educational model through the definition of programme outcomes. For example, the National Qualification Authority of Ireland (NQAI) [117] have eight programme outcomes, six of which are related to skills and competencies which include skill range, skill selectivity, the context in which students can apply skills, the roles students can adopt, ability to learn independently and their insight into methods and processes both local and global. The Higher Education and Training Awards Council (HETAC) has helped contextualize these generic programme outcomes and formed standards for engineering education. For example, HETAC standards require that an engineering graduate - in the context of complex engineering situations - can: “1. manage teams and develop staff to meet changing technical and managerial needs, taking cognisance of ethical responsibilities; and 2. behave professionally and is aware of the responsibilities associated with working in and contributing to a multi-disciplinary team” [118]. Engineers Ireland (EI) articulated six programme outcomes [96] that all engineering programmes are required to achieve; two of which are: criterion A.1.5 (b) that engineering graduates should have the “ability to identify, formulate, analyse, and solve engineering problems” and in criterion A.1.5 (e) that engineering graduates should have the “ability to work effectively as an individual, in teams, and in multi-disciplinary settings together with the capacity to undertake lifelong learning”. Whilst these attributes are desirable and necessary, it is left to the academic community to find the mechanisms to produce graduates that possess these traits. A "best method" of achieving these has not yet been identified.
While the studio-based course adequately dealt with the lower mathematical ability of current students the module remained mostly teacher focused, did not substantially address the professional "soft skills" required by accreditation and statutory bodies, and relied on laboratory apparatus that were both out of context and distanced from the world of electronic engineering. For example, typical laboratory activities might be based on an Amira® [119] dc motor (or equivalent). While it is undoubtedly beneficial for students to gain practical experience, it is believed that students have difficulties relating to these systems because the motor is unconnected; it has no real function, and is out of context. Students view the system as a motor and tachometer encased in a plastic box. Thus a more authentic scenario would be to establish a need for the dc motor rather than just controlling position/speed in isolation to the rest of the process. Based on these perceived limitations, an effort was taken to develop a course component that would address these issues, while also improving student’s abilities to (i) solve engineering problems (ii) work in teams and (iii) learn independently, using an active learning based pedagogy.

3.2 Implementation

A two-pronged approach was adopted: firstly to explore the current best practice trends in engineering education and secondly to investigate, brainstorm and evaluate suitable learning resources. A review of engineering education and education in general, reveals that constructivist approaches to learning seemed to be the best fit for engineering and particularly the project based learning elements of active learning. As noted previously PjBL is devoid of a process for solving the variety of problems that are inherent to the project, but by introducing some element of PBL’s problem solving process into the mix resolves this, and provides a mechanism for the acquisition of professional skills. To this end a hybrid Project and Problem Based Learning (P²BL) methodology was chosen as the appropriate approach. The overarching requirement for the project element was that an authentic electronic engineering system that required control would need to be used, and that the overall module needed to follow the two guiding principles of fidelity and complexity which have to be present when choosing activities to promote professional skills [112].
Thus the chosen device needed to be sufficiently complex to present a number of possible solutions (open-ended problem), require extended teamwork, and yet be sufficiently simple to be solved by applying the basic principles of the discipline applicable from a first course in control. Ideally, it should be both visual and commonly experienced to help concretise [120] the subject matter. A number of different apparatus were investigated, from electric drills to domestic irons, before settling on an inkjet printer as a suitable vehicle to drive learning. This in itself is not new; Van de Molengraft et al. [121] document the use of an inkjet printer as a laboratory experiment in a control course. The printer satisfied the holistic aims for the new course component, in that by illustrating the need for control in everyday objects, students would encounter a more concrete control experience that is closer to their discipline area. Furthermore, the principle control loops involved – control of the print cartridge carriage and print media feed – are relatively simple and suitable for an introductory control systems course. Students can quickly appreciate that the motion control systems for both loops directly affect the overall performance of the printer, and in particular print quality and print speed.

A campus-wide email request resulted in a plethora of offers to collect inkjet printers of different vintages and models. A number of them were the Hewlett Packard DeskJet model (see Fig. 7).

Figure 7. HP Deskjet Printer
As the DeskJet model consists of permanent magnet dc motors and small optical encoder modules with easily accessible control signals, this model type was chosen. Some minor modifications are required to the print carriage PCB to allow the optical encoders to operate properly but otherwise all of the requisite signals can be easily interfaced (See Appendix A for a step-by-step strip down procedure). Harriman [122] documents the real world challenges faced by the Hewlett-Packard Company in designing inkjet printers, and describes the fact that the motion control systems present in the printer directly affect the overall performance of the printer in a variety of ways, and in particular print quality and print speed. A diverse set of constraints act on the print carriage and print media servo designs including: physical constraints from the design of the V-bearings in the carriage and maximum carriage speed for accurate printing; economic constraints from market pressures and the need to use simpler, cheaper mechanical parts; and computational constraints from using a commercially available processor core that only utilises integer operations.

Thus the HP Inkjet Printer provides an authentic real-world problem, which demonstrates the implementation of Control Engineering principles using an everyday piece of equipment that would be familiar to the student. As a means of determining the suitability of this new approach to learning within the control engineering subject, it was decided that it would be productive to trial a short pilot project of the new content. In this way the instructors could focus on the pedagogical aspects of implementation.

The pilot was conducted during the academic year 2007-2008 on year three of the Honours Bachelor of Engineering in Electronic Engineering programme. The first 18 weeks of this course was taught as described in section 3.1 and the remaining three weeks were dedicated to the EBL component. It had originally been planned to allot more than this three week period to the EBL component, but the final section of the traditional course pertained to frequency domain concepts which were prerequisite for other modules, and thus had to be covered by the lecturer. This reduced the available time for the pilot project and it had to be trialled over the remaining three week period. At that time, only six students were registered for the module and these
low numbers partially provided the impetus to experiment with alternative pedagogies. While the numbers are not ideal for research purposes, they did facilitate the implementation process.

3.3 Scaffolding

The student cohort consisted of an equal mix of nationalities (Irish, Spanish and Chinese), of which two were female. The pilot scheme consisted of a weekly student workload of seven hours per week. To support the introduction of EBL into the course the traditional laboratory environment was converted to a learning space (Fig.8) in the manner of a CDIO workspace as described by [73]. This was achieved by reconfiguring the existing laboratory setup to create a discrete informal area for team meetings, reading, etc. and the actual working area where the experimentation would take place. In addition a whiteboard, screen and data projector was installed to facilitate short lectures, presentations, whole class discussions, etc.

In keeping with the EBL philosophy, formal lectures were avoided unless requested by the majority of the student cohort. One of the inherent difficulties with both project and problem based learning is the requirement for students to work effectively in groups and for the instructor to create an environment that facilitates and supports effective teamwork.

The five tenets of effective cooperative learning [46] were used to design the pedagogical environment to support the EBL process as outlined below. A second question that needed to be addressed was the degree of scaffolding that should be provided. In PjBL the learning process is usually supported by formal lectures and the learning involves the application of that knowledge. Ideally, in the PBL process the student is an independent learner and responsible for deciding what needs to be discovered and subsequently finding and learning the requisite material.
However, various research studies indicate problems within this PBL practice. One of the issues of most concern is the learning paradox noted by Schanck and Cleave [123]: "how can students learn by doing what they do, when they do not know how to do what they have to learn." Vermunt and Verloop [124] argue that "the degree of self-dependent learning is not always developed to the optimum level in PBL practice." Effective educational systems should gradually hand over control to the students and Thomas [125] states that the effectiveness of PBL as an instructional method probably depends to a great extent on the incorporation of a range of supports to help students learn how to learn. Greening [126] suggests that these scaffolds be focused in the non-discipline areas (such as group dynamics, metacognition, etc.). Due to the newness of this pedagogy to the students, and the relatively short timeframe of three weeks it was felt that a deliberate student support framework would need to be put in place in order to ease the transition to EBL for both the student and teaching staff. The process was therefore initiated with a workshop to inform students of the rationale for the change, to present the EBL
strategy (Fig. 6), to provide them with resources for EBL, to explore the concept of effective teamwork, and to inform them of their responsibilities within a team.

The students were organised into a team of six and then presented with the following scenario:

You are an electronic engineering graduate working for HP. Your boss calls you into the office and says:

“As you know by now our senior control engineer is out sick and is unlikely to be available for the remainder of the month. Our other engineer is heavily involved with our new LaserJet model. Looking at your engineering programmes I see that you studied control engineering. I have heard great things about you all; that you are fine engineers. We really need to have a prototype ready for the months end but we need to get the control system sorted out, we have to have a controller designed for the print carriage loop. We need that loop working in three weeks time to meet our deadlines. OK? Any questions?”

3.4 Pedagogy

Since the students had no prior experience of problem-based learning, little experience of working in larger teams and relatively little project management experience it was felt that a number of student supports were initially required to avoid frustration and disillusionment. Thus a skeleton project timetable was provided (Table 1) to give a sense of the work required.

<table>
<thead>
<tr>
<th>Week</th>
<th>Action/Deliverable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Become familiar with INKJET printer technology, particularly the control technology for the inkjet print cartridge carriage loop. Deliverable: 10 min group presentation</td>
</tr>
<tr>
<td>2</td>
<td>Interface the printer to the rapid development environment used for controller prototyping based on dSPACE DS1102 controller board. Deliverable: Demo of working interface</td>
</tr>
<tr>
<td>3</td>
<td>Design a controller to control the print cartridge carriage. The control objectives are to move the cartridge as quickly as possible without overshoot. Deliverable: Presentation + demo</td>
</tr>
</tbody>
</table>

Table 1. Skeleton Project Timetable
In week one the students were provided with extra resources, including conference papers and links to suitable articles and websites to act as 'signposts' on the EBL road. A detailed plan of action for week one was supplied (Fig. 9) to illustrate the concept that planning is required, that delegation is necessary and that communication and teaching via team meetings is essential. Students were also given a number of templates relating to meetings (agenda and minutes in particular), and job sheet (Fig. 10) which were to be completed after each two-hour session and acted as an individual record of work done and also as a form of muddy card [127]. The team elected their own co-ordinator and recorder.

<table>
<thead>
<tr>
<th>Day (6/2/08)</th>
<th>Time</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wed</td>
<td>16:00 - 17:00</td>
<td>Introduction to PBL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Teamwork</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Timeframe</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Resources</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Assessment</td>
</tr>
<tr>
<td>Thur (7/2/08)</td>
<td>9:00 - 09:30</td>
<td>Hand out problem, start PBL process, organize subteam, revisit timetable, ensure everybody understands, plan team meetings</td>
</tr>
<tr>
<td></td>
<td>09:30 - 11:00</td>
<td>Read resources</td>
</tr>
<tr>
<td>Thur (7/2/08)</td>
<td>14:00 - 14:20</td>
<td>Team discussion to share information, identify outstanding issues.</td>
</tr>
<tr>
<td></td>
<td>14:20 - 15:00</td>
<td>Hand-up documentation, find resources and address issues</td>
</tr>
<tr>
<td>Fri (8/2/08)</td>
<td>09:00 - 09:30</td>
<td>Team discussion to share information All issues resolved</td>
</tr>
<tr>
<td></td>
<td>09:30 - 10:00</td>
<td>Start creating presentation resolve outstanding problems</td>
</tr>
<tr>
<td></td>
<td>11:00 - 11:30</td>
<td>Work on presentation and resolve problems</td>
</tr>
<tr>
<td></td>
<td>11:30 - 12:00</td>
<td>Practice presentation with feedback from tutor</td>
</tr>
<tr>
<td>Thur (14/2/08)</td>
<td>9:00 - 9:20</td>
<td>Hand up Documentation. Deliver presentation</td>
</tr>
</tbody>
</table>

Figure 9. Timetable for Week 1.

The literature on collaborative learning is clear that group success is predicated upon two factors: positive interdependence and individual accountability [43]. During week one, positive interdependence was achieved by ensuring that team subdivided the work, and that each individual was presented with a critical task. Thus in the planning stage, the authors provided a minimum of six different resources on the general operation of the printer, incremental encoders and dc motors and the team appointed individuals to read and report back on those resources. In addition, one of the team members researched the principles of PWM and stepper motors. Thus each team member had a specific function, which was different from their team-mates and the overall team performance would be diminished if a member underperformed. This is the crux of positive interdependence. This was reinforced by the requirement
of the team to make a presentation on printer technology to the teaching staff and all team members were required to be able to answer questions on the printer.

![Figure 10. Jobsheet/Muddy Card](image-url)
In week two students were required to interface the printer to the rapid development tools available in the laboratory, namely the dSPACE® Integrated Software Environment [128]. This week was less structured and required that the team developed their own schedule of work, group meeting times, delegation of work, etc. As the students had no prior experience of the dSPACE hardware or software, "on-the-job" training was provided and two of the students received a one-hour hands-on demonstration of the dSPACE ControlDesk® software. Positive interdependence (for a group of six) is not as easy to achieve in this task, but the team was encouraged to subdivide into three sub-groups of two and address the software, encoder interface and motor interface in parallel. Once the pair of students that participated in the software workshop was confident that they could use the software they split and assisted each of the other sub-groups in configuring the software and acquiring data that demonstrated that the interface worked.

Minimal student support was provided during week three – aside from encouraging and questioning the team and individual processes and answering general questions. The team’s objective for this week was to design and implement a controller for the print cartridge carriage. Positive interdependence is more difficult to structure into this activity as the team can, and did, choose a wide variety of paths including controlling position or velocity; type of controller (ON/OFF, or P, or PI); and design methodology, trial-and-error or modelling followed by trial-and-error design in MATLAB/Simulink. Positive interdependence was encouraged by insisting that the group of six divide into sub-groups of three and attempt at least two different strategies and clearly distinguish the roles of each team-member via the job-sheet. A second printer, interfaced to the dSPACE board, was given to the team to support this activity.

The cohort perceived the relative difficulty of the problem, and the short time frame, as the motivation to pull together as a group. Individual accountability was achieved through the job sheet and assessment artefacts (presentations and demonstrations with individual question and answer sessions; self-evaluations). Throughout the process, students engaged in face-to-face promotive interaction by discussing ideas...
and problem solving approaches, by challenging each others reasoning and decision making, and by resolving conflicts that arose. Finally, group processing was encouraged by requiring students to perform a self-evaluation.

<table>
<thead>
<tr>
<th>Communicatio n, Contribution &amp; Cooperation (team-work)</th>
<th>Beginning 1</th>
<th>Developing 2</th>
<th>Accomplished 3</th>
<th>Exemplary 4</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Little evidence of support for team activities or contribution towards team tasks. Invested minimal effort. Did not contribute useful ideas during team discussions. Individual did not complete assigned tasks in sufficient time or to the group’s satisfaction.</td>
<td>The individual may have contributed less than others, did not attempt to take initiative, had to be coaxed to contribute, did not complete a few tasks or was untimely in submitting work, demonstrated poor communication skills. Shared a few ideas.</td>
<td>The individual did an equal share of the work, was sometimes proactive in identifying problems and/or suggesting solutions, actively listened, did not try to dominate the discussion, generated some ideas, sometimes encouraged others and assisted others with problems, was able to teach others basic concepts, completed most tasks on time and to the group’s satisfaction. Shared ideas in all group discussions. Supported efforts of others.</td>
<td>The individual did an equal (or above equal) share of the work, generally took the initiative in identifying problems and/or suggesting solutions, demonstrated good communication skills, generated lots of ideas without prompting, generally encouraged others and assisted others with problems, demonstrated good teaching and research skills, completed all tasks on time and exceeded the group’s satisfaction. Worked hard and has very positive attitude.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Technical Performance | Didn’t read resources provided. Didn’t learn from team discussion. Asked no questions, provided no solutions. Is unable to explain the basic operation of the printer or the control loops of interest. | Read resources once, but made little attempt to understand them. Relied on others to do most of the work has an idea of operation of the control loops but explanation is confused and contains numerous errors. Was unable to teach others. | Read and re-read the resources and made real effort to try and understand them. Contributed to the discussion by asking questions and attempting to answer other questions. Is able to explain the operation of the control loop with little confusion and few errors. Was able to teach others and improve the knowledge of others. | Invested a lot of time and effort in reading and understanding the resources and researched other resources to improve understanding. Took a key role in team discussions, asking appropriate questions/providing clear answers. Is able to clearly explain the operation of the control loop with no errors. Was a key element in the group solving the problem. | 

Table 2. Self Assessment rubric
To assist this process an assessment rubric (Table 2) was devised that defined the skills that students should be practising and developing. All team members were then required to reflect on their behaviour within the group on a weekly basis and evaluate their performance using this rubric, and submit a short (half page) written summary of their personal performance evaluation. At end of the EBL component the team was required to present their work to the teaching staff and defend their work in a question and answer session.

3.5 Assessment

The assessment process was somewhat constrained by the existing approved course schedule. In this schedule the subject was to be assessed by a terminal examination (worth 75% of the marks) and a continuous assessment (CA) element (worth 25% of the marks). Students had already attended 18 weeks of laboratory sessions which were assigned 15% of the CA component, they had also undertaken a mid-term examination 4% of the CA marks and therefore the EBL component was worth 6%. The author does not suggest that this was a fair distribution of the marks, but it was decided not to revise the existing course schedule until the pilot process was completed. The author acknowledges that students contributed significant effort, and were subjected to a lot of assessment for relatively meagre marks. The primary objective was to develop a strategy that could be applied to a module taught exclusively through EBL and the author suggests that the process outlined next be viewed in that light.

The assessment methodology in this case will need to reflect the aims of the EBL component, namely promoting independent learning and effective teamworking, and improving the student’s problem solving skills; also in keeping with the philosophy of student-centred learning it was felt that the student should assume some responsibility for the assessment. It was felt that a peer assessment strategy was not fair to the students at that point. They were involved in what was a pilot EBL course, had no previous experience of the process and thus had little or no experience of
objective assessment. From the instructor’s previous experience of using peer based assessment with other project groups it was found that students do not honestly assess their peer group initially and only did so after a significant period of time, so a three week time limit effectively ruled out the process.

Therefore the assessment process is presented in table 3. The minutes of meetings, job-sheet, and self assessment report had to be submitted on a weekly basis. There was also a team presentation at the end of weeks 1 and 3. It was important to ensure that the individual’s performance within the group was accurately reflected in their overall grade, and so two thirds of the assessment grade was dedicated for individual work and one third for the group work element, as detailed in table 3. It was not attempted to assess individual artefacts; they were collated and an overall grade based on the weight of the overall evidence was generated. It was essential to ensure that the three core elements of teamwork, independent learning and problem solving are being assessed and the strategy addressed this issue adequately.

This EBL exercise formed only part of the summative assessment strategy for the control systems course. The students also undertook a terminal open book examination which seeks to examine the complete control systems course. An element of the terminal examination pertained to the EBL exercise.

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4 The project supervisor delivers a fourth year control engineering course using a project oriented learning methodology. Students work in teams of four on a semester long project. Initially peer marking was used, but observations over a two year period indicated that students tended to mark all team-mates high (> 7/10) for the majority of the semester regardless of their performance. These observations have not been published.
### Table 3. Assessment Methods

<table>
<thead>
<tr>
<th>Learning Outcome</th>
<th>(CA) Marks</th>
<th>Assessment Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Team work</td>
<td>2%</td>
<td>Observation, Presentations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Demonstration, Jobsheets, Final</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Project Outcome, Meeting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minutes.</td>
</tr>
<tr>
<td><strong>Individual</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Independent</td>
<td>2%</td>
<td>Self Assessment,Jobsheets,</td>
</tr>
<tr>
<td>Learning</td>
<td></td>
<td>Demonstrations, Observation.</td>
</tr>
<tr>
<td>Problem</td>
<td>2%</td>
<td>Self Assessment, Jobsheets,</td>
</tr>
<tr>
<td>Solving</td>
<td></td>
<td>Demonstrations, Observation.</td>
</tr>
</tbody>
</table>

#### 3.6 Summary

From a pedagogical perspective the course component has been designed adhering to international best-practice in the field of education (constructive alignment of learning outcomes, teaching method and assessment; positive interdependence and individual accountability for cooperative learning; authentic problem and assessment for PBL) using a hybrid Problem & Project Based Learning pedagogy, thus providing a real world authentic problem of sufficient fidelity and complexity to engage the student, promote teamwork, problem solving, and lifelong learning skills. A multifaceted approach to assessment was used, taking cognisance of the need for both team based and individual formative and summative strategies. The relative success of the EBL intervention is evaluated in the next chapter, predominantly through the student voice but also by considering summative assessment results.
Chapter 4: Evaluation and Perceptions

4.1 Evaluation Methods.

Evaluating the effectiveness of pedagogical change is notoriously difficult as there are so many contributory factors and variables. Most frequently, course evaluations, questionnaires, interviews and summative assessment techniques are used to assess the relative success of the change. In this case, the effectiveness of the EBL component discussed in chapter 3 was evaluated in three stages.

In the first instance the component was evaluated using a short questionnaire to determine the student experiences of EBL (Appendix C.2), by conducting a face to face interview with each student in order to elaborate on some of the issues raised from the questionnaire, and through tutor reflections.

The students subsequently went out on six months cooperative placement and upon return to study they were asked to revaluate their PBL experience in light of their industrial experience via a web based survey. The aim of the survey was to determine if the students perceived that effective teamwork, problem solving and independent learning were skills that were beneficial to them in their industrial placement. In addition the survey strove to determine if students believed that the PBL component helped to prepare them for that experience. (Appendix C.1 presents the survey results).

On their return to CIT, the students undertook a control engineering module along with a large number of students that did not experience the PBL component. The control engineering module utilises a project-based learning methodology involving the design and implementation of control strategies for inverted pendulums. Upon completion of this module, these students were again interviewed to elicit their mature reflections on the PBL process, to assess how their experience had prepared
them for this module and, in particular, if they noted any differences between their approach to the module and that of their peers.

4.2 Student Perceptions.

A questionnaire was selected as a quick instrument to initially gauge student perceptions. The design of the questionnaire was informed by a short literature review. A number of generic instruments for evaluating courses, programmes and instructors were identified and evaluated [129], [130]. An advantage of some of these established tools are that their psychometric properties are regarded as being robust, which is generally not the case for tailored surveys. Some disadvantages are that they tend to be generic and developed to evaluate teacher-centred practice. Of the established tools, the Course Experience Questionnaire [131] was identified as the most applicable as it includes statements relating to key skills teamwork, communication, problem solving and analysis. However, many of the other statements (e.g. those relating to instructor effectiveness) were regarded as superfluous. More importantly, for the instrument to be effective in assessing students' perceptions to the EBL component the survey would need to have been administered in previous years. Even then, the low numbers partaking in this pilot would render a comparison or correlation invalid. Therefore, the questionnaire was designed based on existing focused evaluations of problem based learning [132]. This survey was adapted by introducing some of the skills statements from the Course Experience Questionnaire and adding a further statement relating to the practical apparatus.

As the main aims of the teaching reform were to improve teamworking, problem solving skills, and to promote independent learning the format of the questionnaire reflected this by evaluating students perceptions of the problem-based learning methodology, the equipment used, the resources provided, learning achieved (problem solving and teamwork) and the effort applied. Appendix C.2 presents the questionnaire. Students were explicitly asked if they would prefer the control systems module to be exclusively taught through problem-based learning or via the
traditional method and also if they would like to see more problem-based learning introduced into additional modules within the Department of Electronic Engineering. Students were asked to evaluate their perceptions to each of the closed questions based on a balanced seven point Likert scale (Fig. 11.). Each statement was positively phrased which is in keeping with many of the established student evaluation surveys e.g. *Students' Evaluation of Educational Quality* [133]. The questionnaire concluded with four global-type open-ended questions: What did you like about the problem-based learning experience? What did you dislike about the problem based learning experience? How do you think the problem based learning course could be improved? Any additional comments?

2. Do you think that the problem-based learning course has improved your ability to work effectively in a team?

<table>
<thead>
<tr>
<th>Definitely yes!</th>
<th>No improvement</th>
<th>Definitely no!</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 11. Example of Question from Likert Scale Questionnaire

The entire cohort completed the questionnaire and underwent the interview process. Prior to commenting on the results it must be repeated that the student numbers participating in this module were low and a statistical analysis is unreliable. Notwithstanding this, it is beneficial to scrutinise their perceptions of the experience based on the average response, which is tabulated in Figure 12. As mentioned previously, students were asked to respond to each question based on a 7 point balanced Likert scale where broadly speaking, 1 on the scale corresponds to strongly positive and 7 strongly negative.
Chapter 4. Evaluation and Perceptions

<table>
<thead>
<tr>
<th>Question</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1 (1=prefers teamwork; 7=prefers work alone)</td>
<td>2.33</td>
</tr>
<tr>
<td>Q2 (1=yes teamwork improved; 7=no)</td>
<td>2.00</td>
</tr>
<tr>
<td>Q3 (1=learned more with EBL; 7=learned more traditional)</td>
<td>1.83</td>
</tr>
<tr>
<td>Q4 (1=more work; 7=less work)</td>
<td>2.33</td>
</tr>
<tr>
<td>Q5 (1=thinking skills developed; 7=no change)</td>
<td>2.83</td>
</tr>
<tr>
<td>Q6 (1=prefers printer; 7=prefers task)</td>
<td>4.00</td>
</tr>
<tr>
<td>Q7 (1=satisfied with resources; 7=very dissatisfied)</td>
<td>2.83</td>
</tr>
<tr>
<td>Q8 (1=overall very satisfied; 7=dissatisfied)</td>
<td>2.50</td>
</tr>
<tr>
<td>Q9 (1=prefers EBL for control systems; 7=prefers traditional)</td>
<td>3.83</td>
</tr>
<tr>
<td>Q10 (1=more EBL within department; 7=definitely no)</td>
<td>1.83</td>
</tr>
</tbody>
</table>

Figure 12. Results of Questionnaire

It is apparent that the students had strongly positive experiences in the area of teamworking; they felt that they learned more using the EBL approach and that they would like to see EBL introduced into more modules within the Department of Electronic Engineering. The students were positive about the EBL process itself, believed that their thinking skills had improved somewhat and that the EBL approach required more work on their part. Of particular note are the questions that the students had a neutral response to; when giving their opinion on whether the control course should be taught via 100% EBL students five selected point 4 the mid-point of the scale corresponding to ‘a mixture of both’ and one selected point 3. The other question sought to evaluate student’s preferences for laboratory equipment: i.e. either inkjet printer or traditional equipment. The distinct lack of a preference might suggest that the holistic aim of concretising the control systems experience through the use of the printer was a failure.

A number of findings from the questionnaire, particularly the suggestion that the printer was not especially appealing and that students were not keen on a 100% EBL
module, were worth investigating further. To this end, it was decided to interview the students and in the process also obtain a more personalised perception of the EBL process. In addition, it was noted that during the EBL process the students appeared to experience problems transferring prior knowledge to the new problem. The interviews also attempted to explore this issue.

As the students were due to sit terminal exams immediately after the EBL component it was decided to interview the students subsequent to their exams. The interviews took place approximately four weeks after the questionnaires were completed. Each interview was conducted individually, recorded and loosely based around the following questions:

<table>
<thead>
<tr>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>What did you think of the PBL experience?</td>
</tr>
<tr>
<td>Have you any suggestions for improvements?</td>
</tr>
<tr>
<td>How did you find the experience of working in a team?</td>
</tr>
<tr>
<td>What do you think was the most important thing that you learnt?</td>
</tr>
<tr>
<td>The questionnaire indicated that most of you would like a mixture of PBL and the traditional approach. Why do you think that is?</td>
</tr>
<tr>
<td>Would you like to see PBL in other modules?</td>
</tr>
<tr>
<td>Would you have a preference between the printer equipment and the tank (traditional) equipment?</td>
</tr>
<tr>
<td>Why do you think you adopted ad-hoc approaches in the final week to design the controller?</td>
</tr>
<tr>
<td>What did you think of the resources that were provided?</td>
</tr>
<tr>
<td>Did PBL require a greater effort from you compared with the traditional approach?</td>
</tr>
<tr>
<td>What skills do you think you developed during the PBL component?</td>
</tr>
</tbody>
</table>

To maintain anonymity students are referred to as S1 to S6.

A central tone of the interviews is the positive attitude of the students towards EBL. As compared with traditional lecturing students identified that it was more stimulating:

"...you weren't confined to sitting in a class listening to lectures, that you could get up and, like if someday you weren't that...if you weren't that interested, like, you
would have to stay in the class like, but with that [EBL] you could, you could talk to other people and they could help you along” [S6]

“Overall I think it was very good because like you just get stuck in like. There is sometimes you drift off in class. You have to be concentrating in this, like. You kinda have an idea what you’re doing and kinda get into it, like.” [S4]

Other students identified that there was a greater potential for learning and that the learning experience was more practical:

“The first part [of the course] was easier than the second part [the EBL component] but in the second part I learnt a lot of things because with the printer I learned to find information about the printer and control” [S5]

“It’s a good manner of teaching to the pupils. It’s different, but uh maybe we centred more the studies doing practices and not so much theory, theory, theory. I think that that we need to go to the things [experimental equipment] and see what happens” [S3]

“It was different. The tanks were all kinda set up for you; it was just kinda press and play and watch them work. With the printer you had to go away and learn about the chip, the motor – you know? You needed to know what to feed in, what could you feed in” [S4]

Whilst others appreciated the social aspect of the learning and the change from rote learning:

“I can learn something from the other peoples. Get some ideas, discuss and like. It's improved my learning from the course. It's better” [S2]

“But it’s not like the old ways that we have to know everything from day to day – you know? Its like, um ..., yesterday I learnt something. Ok its fine, until the next ... until
before the exam and we go back to the notes and look at it again – that kind of way."

[S1]

This difference, between the “old ways” and the EBL process also caused anxiety for some students. One of the principal causes was the dilemma highlighted by Schanck and Cleave of how to learn by solving problems if you don’t know how to solve problems [130]:

“We are learning something but we find out we didn’t have much information, or enough knowledge to sort out all those problems. So we kinda, like ... even though we can search on-line and all that, but we still don’t know where to go or, like, the things we should search and that kinda stuff” [S1]

“I know for me anyhow, definitely, it was kinda the first time someone sat me down and goes we have a problem here, now go away and fix it like. Um... so you just kinda think ... you weren’t thinking logically and, and the same time none of us ever seen that before so it was kinda like, what do we do here kinda thing?” [S4]

For other students, the collaborative nature of the experience was a difficulty:

“I’m not used to [teamwork] actually, especially when I didn’t know what can I do, what should I do and nobody gave me any help” [S2].

This issue of independence, its relative novelty compared with the traditional structured lecture, also resonated with other students. When asked how the course could be improved, student four, suggested

“More direction, cause sometimes we had a tendency to get groups together and like talk for ten minutes about something that had nothing to do with the thing. And we’d be let away doing it” [S4].
As the student group worked through the EBL process it was clear that the students were poorly prepared for teamwork and found it difficult to communicate, particularly difficult to organise and manage projects such as the EBL one they were experiencing and had little experience or ability in leading teams. The team frequently required refocusing and needed to be encouraged to plan their work, and divide the labour so that the problem could be tackled effectively.

This was recognised by the students themselves and the comments from the students that they found the collaborative nature of the learning challenging was not surprising. Despite this challenge, though, all of the students appreciated the opportunity provided to improve their teamworking skills and strongly believed that the PBL process improved their teamworking skills: "instead of all of us doing the one thing we split up and were coming back together. It's more like a little team on a real project" [S4]. The students perceived that the main advantage of working in the team was that: "if you don't know one thing the other ... you partner, uh, can help you with something and its better" [S5].

The learning outcomes of the EBL component were to develop three key skills: teamwork, problem solving and independent learning. Throughout the interviews there is ample evidence that the students believed that the methodology improved these skills. For example, student number six identified "working in the team and being able to communicate with people" as the main skill developed through the EBL process, and student number three also identifies communication as the primary beneficiary of the process.

A number of students identified the problem solving process as the defining learning experience. For instance student one identified "How we start the problem, the way we think about problem" as the main learning outcome for her. Similarly, for student five it was "to understand the problems and come to develop the problem". The remaining students tended to identify with the ability to learn independently: "I learnt how to look for information" [S2]. "I think it's good, we can actually learn something, learn how to go and search something for ourselves" [S1].
During the EBL component, students experienced real difficulty transferring prior knowledge to the unfamiliar scenario. All of the students in this course had designed and implemented standard controllers (ON/OFF control, proportional controller and a proportional-plus-integral controller) for standard laboratory apparatus (to control liquid level in a tank apparatus) within a conventional laboratory environment and, at a later stage in the course had experienced a formal design procedure (determine model, verify model, design controller, simulate controller, implement) using the same equipment. Yet, faced with the new scenario, all members of the group either reverted to ad-hoc techniques for control or were unable to commence the design process. Whilst the chosen ad-hoc techniques could be formalised as variations of ON/OFF control, the group were unable to perceive this and were unable to formally describe their solution or to apply the formal design experience. The resulting performance of the controlled system was very poor and, even though this performance was very similar to that which they had experienced using the standard laboratory apparatus they could not, even when prompted, relate the two experiences and were at a loss to explain the performance.

While student one openly admitted that she (still) could not relate the two experiences, the remaining students appeared to have crossed this hurdle at the time of the interviews. The defining experience between the EBL process and the interviews was a terminal exam and this might suggest that ‘revising’ for the terminal exam helped in this regard and that some students had not studied or learnt the material previously. The interviews offer some evidence to support this belief: a number of students mentioned that they did not do much work on the problem outside of the timetabled hours as the proximity of the terminal exams was dominating their horizons. Other students claimed that the timeframe to complete the solution was too short and therefore they adopted the simplest solution “ON/OFF is the simpler solution, PI is more complicated. We have no time to try it” [S2] while student four suggested that the unfamiliarity of the learning methodology caused the group to panic a little and just try anything “we weren’t thinking logically”.

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On reflection, both the timing of this particular component with regards to both length and proximity to terminal examinations was not optimal and more than likely had a significant bearing on the student experience. However while it is feasible that students might choose ON/OFF control as it is the simplest option given the timeframe, this does not explain why they were unable to, when questioned, explain that it was actually an ON/OFF controller and appreciate that the limitations of this methodology would result in extremely poor control. Furthermore, it does not explain why students could not relate the poor performance that resulted from their design to similar prior experiences.

In the author’s opinion, the crux of the issue is that the original material was never ‘learned’. This particular issue clearly illustrates the shortcomings of the traditional experimental method where the student completes the exercise almost by rote and does not achieve a deep understanding of the underlying principles. This observation questions the effectiveness of the studio based course, and by extension, the traditional lecture/laboratory model. In this case even though much of the students learning was applied, it is concluded that the application of this learning is still too directed. Referring to Piagets’ formulisation [29], there is some evidence that assimilation occurred but not accommodation - the student’s internal model remained unchanged. The consequence was that students were unable to apply the techniques to a new scenario, and this supports the rationale for introducing more EBL into the curriculum.

One of the objectives of the EBL component was to help concretise the course – to provide students with a relevant, commonplace system that needed to be controlled. The survey results questioned the veracity of that objective. When given a choice between the printer and standard laboratory equipment, the average response indicated no preference. During the interviews however, it emerged that the majority of the students actually enjoyed working on the printer, and even though they were not specifically asked a number of the students specifically mentioned that the printer provided an accurate reflection of how a similar problem would be undertaken in a
professional setting and that it was a very relevant problem for electronic engineering students to work on:

"I think it's better than the tank [standard laboratory apparatus]. Maybe the tank is easier but when we were dealing with the printer, I think I need to learn more" [S2]

"I like to work with the printer because it is more electronic I think" [S3]

"Yes, I like because you get to make a thing with a real problem and its better than ... with the tank its more boring" [S5]

"Yeah I know, probably, yeah maybe in the future I will work in that way. It's the same process. Yeah it's good" [S2 on working with the printer].

There was definitely a cohort that felt that the printer equipment both looked, and was, more complicated and this complexity contributed to the neutral response obtained in the survey. However, it is this complexity which forces students to think more about the system and to appreciate the reality of technical problems that they may face in the future. As alluded to by a number of the students, this complexity also appeared to create a more stimulating learning environment ("I think I need to learn more" [S1] and "with the tank its more boring" [S5]) which is exactly the aim of the EBL process.

The interviews also help illuminate the neutral response to the 100% EBL versus 100% traditional learning environment question. Upon investigation of this point during the face to face interviews the consensus was that the students believed that they needed a "good grounding" [S3] in the theory such as the controller design methodology and the computer aided design tools used or they "would have sunk" [S3]. However, given that the students didn't actually apply much of the theory learned prior to the EBL component, the argument doesn't hold much water. It is presumed that the student's response is based totally on their single experience of EBL. The students found it difficult to imagine an alternative format but that if they experienced EBL first (or undertook a 100% EBL course) then their opinion might be different. Students also believed that such a radical change might pose problems for them. For example, student one mentioned that she would find it difficult coping
because the learning is so different, that when working on a problem the learning is often accidental and can be difficult to internalise and that this is compounded because of the absence of a standard textbook or course notes:

"It's different compared with the original closed-book type of exam. If its closed-book you have to learn everything. But if its open-book we don't really need to know much, and then from the very start - oh OK, its open-book then until the last day [before the] exams Oh we actually don’t know much about it" [S1]

It is interesting to note that in the survey data and throughout all of the interviews students consistently and explicitly mention how the EBL process has really enhanced various transferable skills, but the data and interviews are practically devoid of any comment regarding new technical knowledge that they have absorbed. For example, when asked what did they think was the most important thing that they learnt from the EBL process, students 1, 4 and 5 reflected on problem solving skills, student 2 reflected on communication and learning from others, student 3 spoke about how he learnt to look for and interpret information and student 6 focused on teamwork and communication skills. Considering that these were the main learning outcomes of the component, this was a pleasing result. This perception of an increased generic skillset is understandable given the students own appreciation of their deficiencies in these areas at the beginning of the process and these reflections would appear to be a clear testament of the potential that EBL possesses for developing these skills.

An interesting common thread prevailed, unsolicited throughout all of the interviews, namely students perceived, that the EBL process mimicked how they had previously experienced, or have imagined professional engineering practice to be:

"When you go out to work you don't have to learn everything, but you will have to know how to do it" [S1]

"It's good because if you are going to work you need to do that [the EBL process]. I think that you need to do the things by yourself sometimes so it was good because uh,
you, we get some stuff and then with [unclear] so I imagine that in a job its something like that” [S3]

“It’s [the EBL process] a good thing ‘cause it’s the same again in real life, like. You won’t know everything. You’ll have to go away and look things up in case you blow things up” [S4]

“Yeah, it [teamwork] was good. ‘twas nice to get to, like ... we’ll be doing that in the workplace so it was nice to get a feel for it before going out to do it and stuff” [S6]

This recognition, by the students themselves, of the practicality of the EBL learning process is clearly highly motivating and perhaps accounts, to some extent, for the very positive reactions towards the learning experience.

Upon return from cooperative placement the students were requested to fill in a web based skills assessment survey that was used to measure their perceptions of how useful the skillset that was gained from partaking in the EBL process was in the workplace, and how relevant these skills were to the workplace. Four of the six students responded to the request. Again the results were very positive with students perceiving that the EBL learning experience was relevant to professional practice, and that problem solving skills, the ability to work in teams, and the ability to learn/work independently were very important proficiencies to have in the working environment (Table 4).

The students were positive in their comments to the three open-ended questions: What additional skills do you believe undertaking the PBL module gave you that were of benefit during your cooperative work placement? How would you change the PBL course to improve it and/or make it more relevant to your cooperative work placement experience? Any additional comments? Students were aware of how both communication and independent learning skills had improved by undertaking the EBL process. It was also suggested to increase the amount of time allocated to the EBL process. (Appendix C.1 presents the web survey).
During semester one of the new term, these students were involved in a project based learning module for their second course in control which included students that had not undergone the EBL module. At the end of this process the students were interviewed to elicit their mature opinion of the EBL process, and how their skillset had evolved having been through cooperative placement and a further project based learning module.

| | Percentage of Responses |
|---|---|---|---|---|---|---|
| Very | 1 | 2 | 3 | Average | 4 | 5 | 6 | Not | 7 |
| Having some experience in a professional engineering environment how would you rate the relevance of the PBL learning experience to professional practice? | 50% | 25% | 25% |
| Using the inkjet printer developed my problem solving abilities. | 50% | 50% |
| How important were these skills within your cooperative work placement environment? | 25% | 50% | 25% |
| Undergoing the course improved my teamworking skills | 50% | 50% |
| How important were these skills within your cooperative work placement environment? | 50% | 25% | 25% |
| Undertaking the course improved my ability to learn independently on my own. | 75% | 25% |
| How important were these skills within your cooperative work placement environment? | 50% | 50% |
| How satisfied are you that the PBL experience had a positive effect on your cooperative work experience? | 25% | 50% | 25% |

Table 4. Summary of Results from Web Based Survey

On mature recollection the students were very positive as to the benefits of undertaking an EBL based course especially in light of having worked in industry as practicing engineers albeit for a short time.

"The fact that you are in a team [during EBL] helped as well, you have the experience of being inside in a team, ...being outside in the workplace like, you are in a team there as well." [S6]
“Yeah I was doing a project during my co-op and you know the way of thinking is quite similar to [EBL] project, how to solving the problem” [S2]
“Before I went to work placement I thought this [EBL] was not really going to help ’cause we really didn’t learn as much as the lecturer told us, then after work placement, came back, I think yeah, that was a good idea.” [S1]

From a metacognitive view point the students were aware of how the EBL module had changed their own skill sets.

“I learned to communicate better with people, listen to their points of view and stuff.” [S6]

“Yeah it improved the teamwork.”...“first of all confident with the project and then confident with the presentation [on cooperative placement] and how to do it.” [S2]

“Before I went to work placement I didn’t know did it [EBL] help much, but since I came back from work placement I found that it’s helping a lot because you need to find resources, other information” [S1]

As an attempt to mimic professional practice:

“I think it’s a good experience to do a little of project based learning in college before you go” [S1]
“Maybe not completely but as best I’d say as your going to get in a college, like” [S6]

The author was keen to know how the students now approached the project based learning module in year 4 and if they perceived any differences in the approaches to it between themselves and the members of their cohort who had not undertaken the original year 3 EBL component. The students felt confident in their ability to project manage competently, and maintain a team effort to do so.
"When we were given the problem like, we were able to like split it up, you know, always went and talked to other people to see how they were getting on and stuff, and see were they in any trouble and stuff, and not just like going off and working on your own and not worrying about anyone else." [S6]

It was interesting to note that they did in fact see a disparity in the methodologies used by those who had not been part of the initial pilot.

"I think they are more kind of, rely on lecturer they told them to do, and because I have learned PBL, I've gone through that, I kind of think that I should do the research first before I ask the lecturer." [S1]

"The other group like, they sort of went working on their own an awful lot, they split it up and they didn't really go back talking to each other 'til the end of project report" ... "Two days before they were all at it themselves but then they just combined, but we were always about what way to do the report"... "We split it up as well, but we were always keeping in touch with each other to see." [S6]

The students were prepared to show others a more efficient way of doing things.

"We had one person that wasn't in ours [in third year with cohort], but we sort of co-opted him into our way of thinking." [S6]

4.3 Summary.

Surveys and interviews were used to evaluate the success of this intervention. The initial interviews are surprising in two respects: the dearth of reference to learning of a technical nature and the fervour and frequency with which students mentioned (unsolicited) the 'soft skills' that they developed during the three week EBL component. To accommodate the three week EBL pilot, all of the material on the root-locus and designing simple PI controllers via the ‘rltool’ in MATLAB was omitted from the traditional coursework, in additional to some of the material on
sampled data systems. More EBL implies more sacrifices elsewhere; however it is the author’s opinion that the benefits of developing a transferable skill set outweigh the sacrifices.

Of particular note is the difficulty that students experienced with transferring core knowledge. It was assumed that students would automatically select a PI controller as the 'best' option and the open question would then be how to best design this controller? This however proved not to be the case and the issues that students experienced with the transfer of core principles and techniques illustrates the shortcomings of traditional experimental methods where the student does not achieve a deep understanding of the process and perhaps this is where PBL has a real role to play – let students initially develop ad-hoc approaches and the real problem becomes ‘what is an effective approach?’ leading naturally to the desired outcome.

During the assessment process it became clear that the individual assessment artefacts were better than the group artefacts. The team as a whole were poorly organised and inexperienced; the short timeframe most likely had a negative effect regarding the team’s ability to ‘gel’ and become more efficient. The self assessments were very limited. The students were somewhat resistant to the process of critical self assessment and these were frequently submitted late. When submitted, they were found to be more descriptive than analytical, and overall they reflected upon their experiences in a very surface manner.
Table 5. Student\textsuperscript{5} Grade

It must again be reiterated that the small student cohort does not lend itself to any statistical significance. Table 5 presents a comparison of the grade achieved by the students in both the EBL component and their overall grade for the course. Not much inference can be drawn from the results except perhaps that students tended to do slightly better in the EBL component. Table 6 presents an overview of the terminal examination results. Question 5 pertained to the EBL component. The majority of the cohort answered questions 2, 4, 5 and 6. The score on the EBL component (Q5) does not appear to be significantly different from any of the others that the majority answered. However, more data is required before conclusive statements can be generated.

<table>
<thead>
<tr>
<th></th>
<th>EBL Grade (100%)</th>
<th>Overall Grade (100%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>60</td>
<td>50</td>
</tr>
<tr>
<td>S2</td>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>S3</td>
<td>70</td>
<td>64</td>
</tr>
<tr>
<td>S4</td>
<td>50</td>
<td>26</td>
</tr>
<tr>
<td>S5</td>
<td>80</td>
<td>67</td>
</tr>
<tr>
<td>S6</td>
<td>40</td>
<td>40</td>
</tr>
</tbody>
</table>

Table 6. Summary of Terminal Examination

<table>
<thead>
<tr>
<th></th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>Q5</th>
<th>Q6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Mark</td>
<td>36.3</td>
<td>43.8</td>
<td>60</td>
<td>52</td>
<td>49</td>
<td>28</td>
</tr>
<tr>
<td>No. of students attempted</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

\textsuperscript{5} To ensure anonymity S1–S6 in table 5 does not correlate to S1–S5 in text.
Whilst initially the purpose of the pilot project for the instructors was to determine the feasibility of implementing an active learning pedagogy within control engineering, post industrial experience surveys and interviews support the assertion that undertaking the EBL component prepared students for their industrial placement, and was beneficial in developing the professional skills required in the workplace.
Chapter 5: The Remote Laboratory

5.1 Motivation For The Implementation of a Remote laboratory

During the initial discussions on this work it was felt that the constraints of timetabled access to the laboratory equipment were acting as a barrier to student engagement, and that this lack of access would act as an inhibitor to the process of enquiry for the students. This assertion was confirmed during the interview process with the students and it became apparent that the time allotted for access to laboratory was insufficient, and the students wished that they had had more time to physically interface with the equipment. Savin-Baden et al. [105] have alluded to global online teams acting collaboratively using new ICT technologies, and the use of a remote laboratory provides engineering students with at least, the added capability of devices providing authentic realworld problems being available to all members of a team that may not be physically co-located. To remedy the lack of access situation, and to provide for the future where perhaps not all team members were located in CIT, it was decided to investigate the viability of providing online, remote access to the printer. There were two elements to the approach taken: firstly to explore the whole area of remote laboratories and teleoperation and secondly to implement a remote laboratory using the resources already available within the Department.

5.2 A Brief History of Remote Laboratories

The internet is the primary mechanism for the delivery of remote laboratories. The first, non-educational, uses of the internet to control hardware were in the early 1990s, including the Mercury Project [134], and the UWA tele-robot [135]. With the ability to control hardware remotely via the internet it was only a short time until an educational application arose. The first web-based televant laboratory was developed by Oregon State University in 1995. The system was named Second Best to Being There (SBBT) [136]. The system allowed for remote control of a 3 degree of freedom robot...
through client/server architecture, using UDP/IP. Users received real-time audio and video feedback from the remote hardware. Collaboration between users was a big focus of the SBBT system, and a number of different tools for collaboration were incorporated into the design of the system. Robustness was also of great concern in the design of the SBBT system, with considerable effort having gone into risk assessment.

Web-based access to course materials has become increasingly prevalent in undergraduate teaching, and there have been numerous subsequent projects offering remote access to hardware. There are an increasing number of remote laboratories in operation, with an increasing range of disciplines being taught through this method. Examples include: determination of the speed of light from the resonant behaviour of an inductive-capacitive circuit [137], control of an inverted pendulum [138], and the aerodynamic levitation of a beach ball [139]. Trevelyan [140], for example, provides an excellent summary of remote laboratories throughout the world.

The initial development of remote laboratories was on a laboratory-by-laboratory basis – individual experiments were converted to a web-based mode through a dedicated interface. In recent times, however, multiple experiments are being made available through the same interface. Rather than a direct external connection to the laboratory hardware, an additional user management layer is added. This allows for multiple users to access multiple laboratories in an organised and systematic fashion, and for their access patterns to be monitored in a centralised way. Usually, a student will log on to the laboratory management server, indicate which experiments they wish to queue for, and wait for the equipment to become available to them. In the authors’ opinion, the exemplar in this regard in the area of control engineering is probably the Automatic Control Telelab suite of remote laboratories at the Università di Siena [141]. It provides access to anyone who wishes to perform an experiment using the website, and at the time of writing it provides a range of different experiments from speed control of a dc motor to a 2 DOF helicopter, using predefined or user defined controllers. During the experiment it provides visual feedback in the form of both graphical output and a web camera. It provides for
online parameter changing, and data can be saved upon termination of the experiment.

5.3 Design of The Remote Laboratory

A review of the literature dealing with remote laboratories demonstrates that the vast majority are based on the same software architecture paradigm. Most commonly the architecture is composed as follows: the device to be controlled, a local computer connected to the device, acting as a gateway between it and the remote user, and the associated middleware, through which information is exchanged between the local and the remote computers. As the use of the hardware on both the local and the remote end is essentially proscribed, the major work on the implementation is concerned with middleware. The appropriate data acquisition for the device to be controlled can be selected by the designer subject to technical and budgetary constraints. However, the selection of a particular piece of data acquisition hardware may dictate the use of a proprietary Application Programming Interface (API), which may or may not limit the selection process, due to lack of familiarity with that environment, etc. Examples of such API's include MATLAB/Simulink® [116] or LabView® [142]. Less common instances include the use of programming languages such as Visual Basic or Python. The link between the local and remote computers may be achieved via the use of, for example, Hyper Text Markup Language (HTML), Java, Virtual Reality Markup Language (VRML), or a mix of these technologies.

Gravier et al. [143] identify a number of challenges for, and improvements that can be made in, remote laboratories. These proposals include interoperability between remote laboratories, allowing a physically dispersed ‘workbench’ of devices based on different middleware technologies that a student can access, and to provide a service discovery protocol to allow a student access all available remote laboratories from one point of access. The use of technology to support collaborative learning is discussed in the context of Computer Supported Collaborative Learning (CSCL), and allows group based access to an experiment while using instant communication tools.
to overcome any social isolation barriers that may occur from using such methods. The integration of remote laboratories within Learning Management Systems provides a useful pedagogical tool that could be realized relatively easily and quickly.

It must be noted that the remote laboratory work began at the latter stages of this work and a number of implementation issues described in appendix B.1 delayed it significantly. Therefore, the work that was completed and is described here should be viewed in the context of a proof of concept rather than a finished product. The work focussed on, and was successful in, solving technical issues. The work did not address for example human-machine interface issues and the web pages presented here are functional rather than aesthetically pleasing. For this reason the website has not been published and remains internal to the department. Because of the timing, students have not interacted with the resource and feedback on its usefulness (or otherwise) is not available.

There were two aspects to the design of the remote laboratory, firstly, the choice of hardware, software, and middleware to use in order to implement the system, and secondly, what functionality the website would have. Due to budgetary constraints it was necessary to realise the system with the existing hardware present within the Control Laboratory, and as the students were familiar with the software, it was decided to use MATLAB/Simulink which has a web server toolbox [144], to implement the remote laboratory. Upon consultation with the academic staff it was decided to provide an element of simulation, particularly as students generally do not have access to MATLAB/Simulink outside of college hours, and also to provide the remote laboratory initially to the printer only. Due to time constraints, the main thrust of the work was on investigating the viability of providing remote laboratory access to the printer, and to determine the complexity from a technical point of view of implementing it.
5.4 Implementation of remote laboratory

The general scheme of the application architecture is shown in Figure 13. The hardware and software elements are split into two main blocks: the client side where the user resides and the server side where the physical and control elements are located.

![Diagram of General Architecture of Remote Laboratory](image)

**Figure 13. General Architecture of Remote Laboratory**

- **Client Side**
  - Any computer with an internet connection and a HTTP client such as Internet Explorer. No extra software installation is required of the user.

- **Server Side**
  - **Hardware**
    - High Speed Internet connection.
Chapter 5. The Remote Laboratory

- Server: This was implemented using an existing laboratory Pentium 4 PC with 500MB of RAM and a 10/100 NIC. No changes were made to the PC’s hardware.
- Data Acquisition Card: A dSPACE DS1104 R&D Controller Board.
- Physical System To Control: A modified HP Inkjet Printer.
- Web Camera: A D-Link DCS-1000 IP Camera which can stream video.

Software
- Windows XP Professional operating system.
- HTTP Server Application: Apache v.2.2.11 which is freeware.
- MATLAB R14 SP1 and SIMULINK V. 6.1 to execute the program that generates the simulations, and the real-time control of the printer.
- MATLAB Web server V.1.2.4: This toolbox allows the use of the mathematical and graphical capabilities of MATLAB from a webpage.
- MATLAB Real-Time Workshop V. 6.1: This toolbox generates the C code that, once compiled, will be executed in real-time.
- dSPACE Real Time Interface V. 5.2.5: This software acts as an interface between MATLAB Real-Time Workshop and the DS1104 data acquisition card.
- dSPACE MLIB/MTRACE Interface Library V. 4.5.7: This allows command line interface between MATLAB and the DS1104 data acquisition card.
- MATLAB Control System Toolbox v. 6.1.
When the necessary information is entered by the user it is passed by the HTTP server to the MATLAB web service. This in turn calls the matweb.exe file which passes the parameters to the appropriate m-file. The m-file opens a Simulink model, sets up the parameters required for execution of the model, and then starts either the model simulation or execution of the Real-Time Workshop code, depending on the information entered by the user on the webpage. When execution is finished, the m-file either displays the data graphically in the case of a simulation, or allows the data to be downloaded in the form of a .mat file in the case of both the simulation and of the remote experiment. During the remote experiment a streaming video feed of the printer is passed to the HTTP server for display on the website.
5.5 Implementation Issues

During the initial phase of implementation a number of issues came to light regarding the integration of the HTTP server, MATLAB WebServer, Simulink and dSPACE RTI, the software interface between the data acquisition card and MATLAB Real Time Workshop. As both the simulation and experimentation parameters are entered into a webpage, it is necessary for them to be passed to MATLAB in order for Simulink to be able to utilise them during either a simulation or a remote experiment. The various MATLAB components, such as the MATLAB runtime engine, Simulink, and m-files, all have different workspaces the area where variables created by that component are stored, and kept local to that workspace (Fig. 15). The main issue was that any parameter that is initialised on the website needs to be accessible by all of the workspaces. Appendix B.1 illustrates solutions to the problem for both the simulation and the remote experiment.
5.6 The Website For The Remote Laboratory

The website was intended to be as simple to use as possible. The layout of the sections where the parameters are entered are designed to match the simulation parameters page of Simulink, providing a visual link back to the work that students carry out in the PC’s during their design process.

![Remote Laboratory Website Homepage](image)

Figure 16. Remote Laboratory Website Homepage

When the user connects to the website they are presented with the homepage as illustrated by Figure 16. From this page a user can navigate to either the simulation page (Fig. 17) or to the remote experiment page (Fig. 20).
In the simulation section of the website a user can choose to design a PID controller for a FeedBack Instrument Systems Level and Flow process [145], a TQ Twin Tank process [146], or the Inkjet Printer. The students are familiar with these processes from previous experience in the Control Systems Laboratory. To maintain a link for the student between their laboratory sessions and the website, the parameters section is designed to mimic the simulation parameters dialog box in Simulink. The user can input different solver types, the sample rate and the simulation time required for the simulation. Once the user submits the information to the webpage it is sent to Simulink for execution.
When the simulation is finished MATLAB returns a graphical output of the controller response, and the resultant .mat file can be downloaded for examination later.

Figure 18. Result of Simulation

Here we use a PID controller designed in simulink to control the position of the inkjet print head using a DSpace DS1104 Data Acquisition Card.

The PID and the experiment parameters are entered on the remote experiment page. The results of the experiment can be down loaded to view later.

Figure 19. Experiment Descriptor Page
When a user navigates to the experiment page, they are initially brought to a descriptor page (Fig. 19). From this page the user can navigate to the remote experiment page (Fig. 20).

![Figure 20. Remote Experiment Page](image)

On the remote experiment page a streaming video of the printer is presented to the user. The PID controller parameters are entered here along with the setpoint, sampling rate, and simulation time. When these parameters are submitted the experiment is executed with visual input from the web camera. Once the experiment is completed the resultant .mat file can be downloaded for later examination.

### 5.7 Further Work

Due to time restrictions only a basic website from a design aspect was designed. While both the simulation and the remote experiment elements operate correctly, there are no security restrictions or user usage logging elements in place, and access only to one device is provided. However this work has provided a ‘proof of concept’,...
and thus provides an impetus to provide a fully operational suite of remote devices, most likely being those apparatus' available within the Control Laboratory at CIT accessible from a single point of contact. While the existing website is functional, it is not optimally designed from either an aesthetic or a technical point of view. Suitable collaboration with the Computer Science Department may produce an alternative design, to give more immediate results and make the process more interactive by using for example a java based platform. As the website will be used by a web media savvy audience, collaboration with the Multimedia Department may produce a website better suited to engage with that audience.

5.8 Summary

It was determined that there was a need to provide the students with access to the physical equipment outside of the time allotted for access to the laboratory. Taking cognisance of this fact it was decided to investigate the viability of providing remote access to the printer via the internet, thereby providing a pedagogical tool that could be further enhanced using new ICT technologies, and used in the future by geographically distributed teams in a collaborative manner.

A website providing the student with the capability of running simulations and operating a remote experiment was designed and implemented using the existing laboratory equipment and the existing MATLAB\Simulink rapid development tools.
Chapter 6: Outlook

6.1 Introduction

From Chapter 4 it can be concluded that students perceived that the EBL component was beneficial in developing the targeted skill set. Furthermore, the component highlighted some limitations of the existing teaching pedagogy. Principally, students’ ability to apply the techniques and principles of the control systems module to new scenarios was limited. Logic, supported by the constructivist pedagogy, suggested that delivering the entire module through EBL might address the latter issue while providing further opportunities for students to practice problem solving, teamwork and independent learning for a significant duration and further develop these skill sets. In considering this issue the author faced a number of dilemmas relating to the design of the EBL module. Key questions related to whether the printer was sufficiently challenging for a thirteen week module and whether the printer would adequately support introductory control systems concepts. In relation to the first issue the author needed to determine the nature of the problems that the printer was likely to pose to the students – hence the enquiries that they would address. In addition, it was critical to determine if there was sufficient work to occupy a team of four students for thirteen weeks. If the project was not sufficiently complex then the team would not perceive that a team of four was required and this would encourage individuals not to contribute – this is the essence of the positive interdependence concept [43]. While the team size could be reduced, the majority of the literature suggests a team of four is probably best for inexperienced students – it is not too difficult to manage but still presents sufficient difficulties to challenge students [147]. With respect to the second issue, considering controller design, for example, it is of interest to the author to determine if introductory design practice (PID controller design using root-locus or tuning rules) would yield adequate results for the printer system. If introductory concepts and techniques did not work, then students might get disillusioned as they might perceive the project as a failure or they would be required to understand material generally considered to be outside the scope of an introductory control systems course. While the literature on designing enquiry based
modules is relatively scant, that related to the engineering discipline generally recommends a proto-typing process as most fit for purpose. For example, Chang et al., commenting on the design of problem-based learning modules, suggest that instructors should “study the feasibility of the project and to organize the project tasks. For instance, instructors may request, in advance, teaching assistants (TAs) to build up a prototype of the proposed system for the PBL” [148]. The author adopted this process to address these two issues.

The following section outlines a template for a thirteen week module and examines in greater detail some of the enquiries that a team might undertake. The author focused on 13 weeks as this is the standard employed by CIT. The description should be interpreted as enquiries that the students may undertake and results that the students may generate. The following sections are not intended to be prescriptive, teacher centred or to suggest that these are the only routes that a student team may follow – rather that these are the likely routes (based on logic and accessibility of concepts) and example results.

6.2 The Printer As a Vehicle For Enquiry

In keeping with the literature on active learning (e.g. Kolb’s Learning Cycle) active experimentation and concrete experiences are central to the learning experience. They are key to students understanding the techniques, and appreciating the limitations of these techniques. This forms the foundation for the proposed EBL module. Furthermore, the guiding principle is that every student should experience some form of modelling, controller design, implementation and basic evaluation. Table 7 provides a summary blueprint for a 13 week module and is based on a formal design procedure (Fig 21). It is assumed that students undertake the module in teams of four and within the team each student adopts a variation of the modelling and controller design processes. In this way students can compare and analyse results and begin to appreciate the advantages and limitations of these techniques. Each student would be expected to be proficient with the technique applied by them and to be
familiar with all techniques applied by the group. This proficiency may be assessed through either a formative or summative assessment process.

Figure 21. Generalised Controller Design Procedure
<table>
<thead>
<tr>
<th>Time</th>
<th>Heading</th>
<th>Work to Complete</th>
<th>Deliverables</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Week</td>
<td>Define control objectives and project plan.</td>
<td>Create project plan. Which loop is to be controlled? Expected performance of controlled loop.</td>
<td>Project Plan.</td>
</tr>
<tr>
<td></td>
<td>Modelling</td>
<td>Review possibilities. Choose techniques (First principles, time domain, graphical, frequency domain, state-space). Apply two variations of two techniques (different data, different assumptions).</td>
<td>Mathematical Model</td>
</tr>
<tr>
<td></td>
<td>Model Validation</td>
<td>Compare model performance with other models/other groups/using different data/different assumptions. Identify most suitable model. Identify limitations of techniques applied.</td>
<td>Paper on system identification</td>
</tr>
<tr>
<td></td>
<td>Controller Design</td>
<td>Apply two controller design techniques to the developed models. Options include PID tuning rules, root-locus, frequency response techniques, IMC, state feedback control.</td>
<td>Paper on controller design</td>
</tr>
<tr>
<td></td>
<td>Simulation</td>
<td>Define models &amp; controllers in CAD software e.g. Simulink. Simulate &amp; analyse performance. Check specifications and revise design as required.</td>
<td>Simulation achieving required performance</td>
</tr>
<tr>
<td></td>
<td>Implementation</td>
<td>Implement controllers, measure performance, compare with simulation. Account for differences, compare with other designs. Observe limitation of techniques</td>
<td>Report</td>
</tr>
</tbody>
</table>

Table 7. Summary Blueprint for a 13 Week Module

The onus is placed upon the student to project manage the whole design process, and in this way the emphasis is shifted from being instructor led to a more student centred approach, where the instructor adopts a facilitator's role. Upon receiving a problem statement, and the experimental apparatus, student groups need to become familiar with the equipment on a conceptual level, broadly understand the control problems, select one of these problems and establish expected performance
requirements for that problem. In addition they need to establish a typical controller
design cycle (Fig. 21), and plan their project about that cycle. This effort culminates
in a project plan that guides the group through the module.

Subsequent to the project plan it is possible that groups would choose many different
routes. For example groups could select a first principles modelling approach, that
doesn’t require experimental approaches. However, it is anticipated that most groups
would like to experience the equipment in operation, and as this needs to be achieved
at some stage (either during the model validation, or the controller implementation
phase), it may be as well to engage with experimentation from the outset. Groups
need to identify the optical encoders, establish how they work, interface them to the
PC, and test that everything performs as anticipated. A similar exercise needs to be
performed with the motors. Cognisance must also be taken by the student of the
signal conditioning requirements of the interface between MATLAB® and
Simulink® [116] and the printer, in this case a dSPACE data acquisition card [149].

Logically, the next step is to develop a mathematical model for the process. Table 7
suggests a variety of avenues through which this may be achieved. From first-principles it is relatively trivial to arrive at the following model structure relating
input voltage to shaft position for a dc motor [150], [151]:

\[
G(s) = \frac{K_t}{s((Js + b)(Ls + R) + KtKe)}
\]

Kt = electromotive force constant
Ke= back electromotive force constant
J = moment of inertia
L = electric inductance
R = electric resistance
b = damping ratio

Eqn. 6.1

The coefficients Kt, Ke, J, L, R, and b need to be determined either by
experimentation or if available, from a technical data sheet for the motor. In many
cases the relative effect of the inductance is negligible compared to the mechanical
motion and can be neglected, thus causing the back emf to be indistinguishable from
the friction giving:
Chapter 6. Outlook

\[ G(s) = \frac{\frac{Kt}{R}}{s^2 + \left(b + \frac{KiKe}{R}\right)s} = \frac{K}{s(\tau s + 1)} \quad \text{Eqn. 6.2} \]

where the coefficients \( K \) and \( \tau \) represent the gain and time-constant of the system.

In a first course in control a model is frequently determined by applying simple input stimuli e.g. a step signal to the plant under test, graphing the response and reading the gain and time constant from the graph. There are effectively two options: the trial-and-error approach applies a stimulus and from the resulting graph, the model structure, order and coefficient are determined. This is not always successful as a suitable stimulus might not be applied. The alternative is to use some a priori knowledge from the system, gleaned perhaps from a perusal of textbooks/internet sources, to determine the model structure and perhaps model order. This a priori knowledge establishes that the dynamics of the print cartridge and print media feed loops contain an integrator, and either from this analysis or from a consideration of the physical operation of a dc motor, groups should determine that the standard ‘step’ test is not applicable to this system. Therefore, to identify the coefficients an impulse response or a response to a pulse needs to be used.

![System Identification By Experimentation](image)

Design constraints which then need to be considered are the shape of the applied pulse, i.e. the pulse height and pulse width, the ratio between height and width, the
sampling rate that will be required, whether the process is time invariant, etc. Note that the printer used is an old model, subject to much wear and tear, has worn belts and cogs, and the motors are well used, providing a good example of a time varying system whose characteristics change over the course of an experiment, and illustrates the need for multiple data sets to enable good system identification. Figure 23 demonstrates an example of a typical response curve from the printer.

![Typical Printer Response](image)

Figure 23. Typical Printer Response

Once the experimental data is available to the student, there are a number of different approaches which can be taken to derive a model. Typically these include graphical identification methods, and computational identification methods such as Least Squares, or using CAD tools such as MATLAB System Identification Toolbox [152]. In this case the system was identified graphically by integrating the pulse to determine the input setpoint value, and the process gain is determined by dividing the steady state output by the input set-point value. The time constant is the time taken for the output to reach 63% of the final value.
Table 8. Derived Transfer Functions

<table>
<thead>
<tr>
<th>Model</th>
<th>Transfer Function</th>
</tr>
</thead>
</table>
| Graphical\(^6\)                           | \[
\frac{1.6421}{0.0647s^2 + s}
\]                                                                                  |
| Sysid ToolBox oe110\(^7\)                  | \[
\frac{1.6420}{0.0349s^2 + s}
\]                                                                                  |
| Sysid ToolBox oe121\(^8\)                  | \[
\frac{-1.535s + 2947}{s^3 + 63.74s^2 + 1794s}
\]                                          |

Figure 24. Comparison of Simulated Responses

As can be seen from Table 8 and Figure 24 a number of different models can be determined from the same experimental data.

Again the decision as to which one to use as a representation of the physical model lies with the group; do they need to use the higher order model which includes the

\(^6\) Determined graphically  
\(^7\) Generated using Output Error Parametric Model by System Identification Toolbox  
\(^8\) Generated using Output Error Parametric Model by System Identification Toolbox
mechanical and electrical coefficients of the physical system, or keep the model as simple as possible? For this component, prerequisite knowledge includes familiarity with linear systems, and the dynamics of first-order and integrating systems. Presumably, students would also have covered a course in Laplace or Z-transforms. Relating and applying these concepts is the key learning. Once the decision is made then the model needs to be verified and this is generally carried out by applying an appropriate input signal to both the model and the physical system simultaneously and comparing the output of both systems.

Figure 25. Results of Model Verification

Once the chosen model has been verified the group needs to choose an appropriate controller structure (on/off, lead/lag compensator, PID controller) and a design methodology. For a first course in control, the textbooks most accessible to students would in general illustrate root locus design and a PID control approach using the Ziegler-Nichols tuning rules. More advanced textbooks such as [153] provide tuning rules for a range of different processes. Advanced techniques such as Internal Model Control (IMC) [154] may be used, as well as CAD based root locus controller design tools such as MATLAB rlttool [155], and again the decision is left to the group. Focusing on the design of PID controllers via tuning rules it is evident that most of the rules include a time-delay. The most relevant model structure for this system is the First Order Integrator Plus Time Delay (FOIPD) model structure, this may
prompt the group to revisit their initial modelling data and recognise the time delay present in the system (Fig. 26).

![Figure 26. Model Time Delay](image)

$$G(s) = \frac{K}{s(\tau s + 1)}e^{-\tau s} \quad \text{Eqn 6.3}$$

$$G(s) = \frac{1.6420}{0.0349s^2 + s}e^{-0.008s} \quad \text{Eqn 6.4}$$

This model structure precludes the Zeigler-Nichols techniques as they assume a First Order Lag Plus Time Delay model. However suitable controllers may be designed using RLTtool or the tuning rules available for FOIPD models in [153] and their suitability can then be analysed. Prerequisite learning involves a basic understanding of the P, I and D terms of the PID controller and their influence on closed-loop performance and stability. This could be achieved by the group investigating P, PI, PD and PID designs in parallel and discussing the design challenges (stability, complexity) and comparing performances (settling time, percent overshoot, steady-state error). An application of the most applicable tuning rules [153], (Table 9),
should illuminate the design and lead to the conclusion that PD is the most appropriate compensator structure as the system already includes an integrator. In simulation, at least; it is evident that an additional integrator only serves to destabilise the loop. A similar conclusion can be arrived at through the root-locus design tool in MATLAB. This tool may be used in a blank trial-and-error fashion by varying the compensator gain and pole/zero locations and observing the resulting performance. Alternatively, standard text books may inform a more systematic approach to the design problem. Either technique should result in coefficients similar to those of Table 9 and the simulated results of Figure 27. While the proposed timetable (Table 7) proposes that the controller design and simulation components be decomposed into two separate activities, as a learning process it makes more sense that they be combined so that students can immediately see the results of the design. However, it is still useful to present the simulation as a separate exercise so that groups are encouraged to collate the results of their simulations (assuming four different designs) and draw some conclusions from those designs. In this case a PD controller is the most appropriate structure and the root-locus tool would appear to deliver the optimum PD coefficients.

<table>
<thead>
<tr>
<th>Rule</th>
<th>P</th>
<th>I</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>McMillan [156]</td>
<td>388.82</td>
<td>696</td>
<td>0.56771</td>
</tr>
<tr>
<td>Viteckova et al [157]</td>
<td>27.19</td>
<td>0</td>
<td>0.92718</td>
</tr>
<tr>
<td>O'Dwyer [158]</td>
<td>2.637</td>
<td>0</td>
<td>0.0899</td>
</tr>
<tr>
<td>Minimum ISE [159]</td>
<td>49.257</td>
<td>0</td>
<td>1.6797</td>
</tr>
</tbody>
</table>

Table 9. PID Parameters Derived From Different Rules
Using RLTool a PD controller can be designed to give parameters:

$$P = 24.6 \text{ and } D = 0.35$$

Figure 27. Results of Simulation of Tuning Rules

Figure 28. Simulation of RLTool PD Controller Design
A selection of these designs can then be implemented on the printer and analysed relative to the initial performance specifications. In parallel, different designs can be compared against each other and against simulation results. Designs may need to be revisited if time allows. Crucially, the group must decide whether it is likely to be more beneficial to revisit the modelling or revisit the controller design? A comparison of simulation versus measured performance may inform this choice. For example, comparing figures 27 and 29 it is apparent that there are broad similarities. The McMillan design results in high overshoot in both cases while the O'Dwyer design is the slowest. The performance of the other designs is very similar. This would suggest that the design is based on a good model and if improvements are required then revisiting the controller design is likely to be more profitable. A key question is of course, if improvements are possible e.g. is the control signal saturated? Again, the design should be evaluated on a variety of different input signals and conclusions drawn from across groups. The wider issues of performance and robustness metrics may also be considered, but their inclusion is dependant on the time available, the instructor's teaching philosophy, their inclusion in follow on modules, etc.

Figure 29. Implementation of Controllers
Figure 30 illustrates the closed loop servo response to a revised PD controller of:

\[ P = 24.6 \quad D = 0.435 \]

achieved through experimental methods.

![Figure 30. System Response Using PD Controller](image)

Thus it can be shown that the printer would act as a suitable vehicle for Enquiry Based Learning, allowing students to follow the generalised controller design procedure in a manner dictated by the students themselves.

### 6.3 Summary

This chapter has proposed a blueprint for a thirteen week EBL module motivated by the success of the EBL component described in chapter 3 and evaluated in chapter 4. While the initial EBL component was delivered and evaluated in the academic year 2007-2008, the proposed EBL module could not be implemented as staffing arrangements were changed and the new instructor was not keen to augment a new module with an unfamiliar pedagogy. For the academic year 2009-2010, the project
supervisor will be responsible for a similar module in a similar programme and it is intended to implement and evaluate the EBL module then.
Chapter 7: Conclusions & Future Work

7.1 Conclusions

There has been a gradual shift in the emphasis of engineering education from the old traditional hands-on approach towards a more purely theoretical one, and the consequent diminution of the transferable skills of teamwork, problem solving and communication. Calls from both industry and national accreditation bodies have led engineering educators to investigate different approaches to learning in order to reintroduce these skills to students. Behaviourist and constructivist approaches to learning are student centred which allow the learner to construct their own reality from the situations and scenarios that they encounter – they make their understanding based on things that they experience. In particular experiential learning theory emphasizes the role of experience in learning and the importance of developing links between classroom practices and the real world. These ideas provide a bridge between the traditional approaches to engineering education where laboratory sessions are a means to illustrate particular elements of theory, and the more inductive approaches to learning where the laboratory session is the vehicle by which the theoretical elements are introduced. Active Learning and in particular Problem and Project Based Learning, provide engineering educators with a proven pedagogy, based on social constructivism, which is particularly suitable as a mechanism for producing graduates that possess those traits of teamwork, problem solving and communication so desired by industry. However adequate thought must be given to the authentic assessment strategies required to test both the ‘soft skills’ and the ‘hard skills’ adequately and fairly.

In an attempt to place the student at the centre of the learning process a three week EBL module was implemented, using the Printer as a vehicle for enquiry, within the existing Control Systems subject at the Department of Electronic Engineering at Cork Institute of Technology. This module was designed using international best-practice in the field of education (constructive alignment of learning outcomes,
teaching method and assessment; positive interdependence and individual accountability for cooperative learning; authentic problem and assessment for EBL), using a hybrid Problem & Project Based Learning pedagogy in which the emphasis is shifted from the instructor having a lead role to one where the instructor adopts a facilitator's role. A real world authentic problem of sufficient fidelity and complexity to engage the student has been provided, and the main aims for this component were to promote teamwork, problem solving, and lifelong learning skills. A multifaceted approach to assessment was used, taking cognisance of the need for both team based and individual formative and summative strategies.

To evaluate the intervention, surveys have been relied upon to provide a perspective on student opinion and interviews to probe in depth. The initial questionnaires and interviews reveal a mixed reaction to the effectiveness of the resource in concretising the subject matter, but also illuminated the students perceptions that their previously lacking professional 'soft skills' had been enhanced by undertaking the three week EBL component. Based on the outcome of the initial interviews, it was appropriate to extend the research and investigate student’s perceptions of the relevance of these skills in their industrial context and determine how well they felt that the EBL component prepared them for their industrial placement. All of the students interviewed found that they required these particular skills in their six month work placement and were of the opinion that the EBL component was beneficial in developing those skills. And indeed feedback from the employers as part of the cooperative placement assessment process, verified that the students possessed those ‘soft skills’ to some extent. A cycle of skill development, application and reflective evaluation, has been completed and the student’s testimonies indicate the effectiveness of the intervention. This research also collaborated commentary found elsewhere in the literature regarding the immediacy of skill development [160]. In this case, it was only after a period of time that student fully realised the benefit of the experience and the extent of the learning.

The provision of remote experimentation was investigated, was found to be feasible within the context of budgetary and technical constraints, and a basic website
allowing both access to the printer for remote experimentation, and a simulation environment based on MATLAB/Simulink® was developed. The use of such a pedagogical tool perhaps integrated into a learning management system such as Blackboard [161] potentially provides both the Department and the Institute with the capability of offering an engineering curriculum, both practical and theoretical, in a distance education format, thereby enhancing service to students.

7.2 Future Work

The appropriateness of EBL for engineering has been confirmed and this component could be easily be integrated into a blended learning [162] environment with other subjects in the curriculum. For example, in computer systems, students study microcontrollers such as the Microchip® PIC family [163]. To date, there has been little integration across the curriculum between control systems and computer systems within the Department. The printer provides an obvious candidate that requires both control and embedded systems. An authentic problem for the computer systems course would be to implement the (PI) controller designed in the control course on a PIC. Again, this is not without a cost – a great deal of planning, module revision and some loss of content. However to achieve this would require some proselytising - many colleagues within the faculty remain to be convinced of the advantages of an active approach to learning. That may yet prove to be the biggest obstacle to achieving an integrated curriculum in Electronic Engineering.

The proposed the EBL-based control systems module has not yet been implemented. This is primarily due to a significant course restructuring that the Department undertook last year. Lack of interest has resulted in the ab-initio B.Eng. (Hons) course being discontinued and the previously streamed B.Eng. (Ord) has been unified into a single course, and a one-year add on developed to achieve the B.Eng. (Hons). There are two control modules in the one year add-on, and in the coming academic year it is intended to run the EBL module as presented in Chapter 6 and to continue to evaluate both the effectiveness of the intervention and students perceptions of the methodology.
The design and implementation of the website was done mainly as a 'proof of concept' in order to confirm its viability. The operation is very basic and lacks both security and logon features. It has only been designed for one piece of equipment. Further collaboration with the appropriate Departments within the Institute are required to design a professional website, which would allow for example, provide a single point of contact for access to multiple pieces of equipment, from different disciplines, within the Institute.
Appendix A: HP Printer Stripdown

A.1 Stripdown Sequence
We have used a 900 series HP inkjet printer.

Before You Begin
You will need a T10 Torx driver and some latex gloves if you want to avoid getting ink on your hands once the case has been removed.

Remove the Case

1. Remove the two screws at the top of the case

2. Remove the rear access door and press the release tab in both upper corners of the opening.

3. Open the hinged cover and release the two "claw" latches using a slot screwdriver. One is in front of the Service Station and the other is on the opposite side in the same relative position. These are a bit tricky to release and patience is required.

All of the requisite components are now accessible.
We now need to remove the print head carriage to access the pins on the optical encoder.

Push this plastic wheel back with a screwdriver and slip the belt off.

Slip the belt off the cog on the other side.

Slip the encoder strip off from this side and disconnect at other end. Pull out and note orientation.
Appendix A.

Remove the Torx screws from the silver bar and remove bar

Pull off the ribbon connector and fully disassemble.

We can now access the pins on the optical encoder. This is necessary because the power for the encoder is normally supplied from the pcb when the printer is plugged in. As the printer is not now externally powered we must access the +5 pin in order to supply this ourselves from either the DAQ card or a power supply.

Details on these types of encoders can be found here: http://www.avagotech.com/products/motion_control_solutions/incremental_encoders/transmissive_module/heds-9700%23h51/
We can solder a wire between the encoder pin and the ribbon cable connector pin 5 (this is arbitrary, any from 4 up will do).

Looking at the ribbon connector above (Pin 1 is topmost pin):

<table>
<thead>
<tr>
<th>Encoder Pin</th>
<th>Ribbon Connector Pin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel A</td>
<td>3</td>
</tr>
<tr>
<td>Channel B</td>
<td>2</td>
</tr>
<tr>
<td>Gnd</td>
<td>1</td>
</tr>
<tr>
<td>+5V</td>
<td>5 in our case</td>
</tr>
</tbody>
</table>

Reattach the ribbon cable to the carriage head.

Reassemble the printer carriage assembly in reverse order.
Appendix A.

We can now access the pins of the encoder from the ribbon cable at the back of the printer; the bottom pin of the cable is pin 1.

<table>
<thead>
<tr>
<th>Encoder</th>
<th>Ribbon cable pinout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel A</td>
<td>3</td>
</tr>
<tr>
<td>Channel B</td>
<td>2</td>
</tr>
<tr>
<td>Gnd</td>
<td>1</td>
</tr>
<tr>
<td>+5V</td>
<td>5 in our case</td>
</tr>
</tbody>
</table>

Accessing the motor that drives the print carriage and the encoder/motor for the form feed is a much easier procedure.

They can all be accessed from the white connector plug.
We now have access to all the requisite signals we need to use the printer. These can be interfaced to an appropriate data acquisition card (capable of taking incremental encoder signals).
Appendix B: MATLAB Code

B.1. Solutions To The Implementation Problems.

Simulation:
The base workspace for a simulation launched by the ‘sim’ command is the MATLAB workspace by default, however if the workspace of the function that invokes the sim command is to be used as the base workspace of the simulation, the simset option “SrcWorkspace” must be set to ‘current’ to do this, thus enabling the parameter passed by the website to be available to Simulink for the simulation process.

Firstly simset is used to change the workspace to the m-file that calls the sim command:

```matlab
options = simset('SrcWorkspace','current');
```

Then the various parameters are sent to Simulink, for example:

```matlab
set_param('picnt9/Step', 'After', 'simstepsize');
```

The Simulink simulation is then executed:

```matlab
sim ('picnt9',[],options);
```

Remote Experimentation:
As the ‘sim’ command is not executed during a remote experiment a different solution was derived to enable the parameters to be seen by the different workspaces.

Firstly the variable value is passed into the m-file from the website:

```matlab
prop= str2double(h.pgain);
```

This variable is then reassigned to the MATLAB workspace:

```matlab
assignin('base','pgain',prop);
```

Then the various parameters are sent to Simulink, for example:

```matlab
set_param('picnt9e/PID Controller', 'P', 'pgain');
```

The realtime experiment can then be commenced:

```matlab
rtwbuild('picnt9e');
```
Once the problem with the separate workspaces was resolved, the simulation side of the design worked correctly, the parameters were passed successfully to Simulink and the simulation results were passed back to the webpage effectively. However, with the experiment element, a problem occurred at the interface between MATLAB Real Time Workshop (RTW) and dSPACE Real Time Interface (RTI). During the real time build process, the compiler gave a number of errors and terminated the build process. Upon investigation, it was found that the parameters were being passed correctly to the Simulink model, and the issue was with the communication process between RTW and RTI. A software bug between the two particular releases of RTW and RTI which causes the compiler to use the `rtwbuild` instead of the `rtihuild` command was found to be at fault. To overcome this necessitated a change to both the software and hardware to the implementation described in chapter 5.

B.2. Simulation M-File

`Simulate.m`

```matlab
function rs = simulate(h)
    % RS SIMULATE(L) accepts variables passed to it from webpage parameters.html. It converts these variables to numeric values and passes them to a Simulink model.
    % This model is then executed and returns HTML output in string RS.
    % Handle H is the structure created by matweb.
    % Author(s): Dave Hamilton
    % CIT

    % Get unique identifier (to form file name)
    mlid = getfield(h, 'mlid');

    % Set directory path for storage of graphic files.
    cd(h.mldir);
```
% Cleanup jpegs older than 1 hour.
wscleanup('ml*tep1.jpeg',1);

% Take the parameters in from the webpage and convert
% them to numeric values.
pgain = str2double(h.pgain);
igain = str2double(h.igain);
dgain = str2double(h.dgain);
simend = str2double(h.simend);
fstep = str2double(h.fstep);
simstapsize = (str2double(h.simstepsize)/10);
open picnt9; % Open the simulink model
options = simset('SrcWorkspace','current'); % set the appropriate workspace

% Here the appropriate transfer function is selected
% determined by user input from the website.
if (isfield(h, 'select'))
    plant = getfield(h, 'select');
if strcmp(plant, 'Twin Tank')
    gs=tf(4,[60 1]);
    set_param('picnt9/LTI System', 'sys', 'gs');
elseif strcmp(plant, 'Level and Bow')
    gs=tf(4,[160 1]);
    set_param('picnt9/LTI System', 'sys', 'gs');
else
    gs = tf([1.6420],[0.0349 1 0]); % printer transfer function
    set_param('pient9/LTI System', 'sys', 'gs');
end
end
Appendix B.

% Here the appropriate solver type and solver is selected
% determined by user input from the website.

if (isfield(h, 'solvertype'))
    solvertype = getfield(h, 'solvertype');
    if strcmp(solvertype, 'Fixed-Step'); % Fixed step solver
        set_param('pient9', 'Fixedstep', 'fstep');
        set_param('pient9', 'InitialStep', '0');
        set_param('pient9', 'MaxStep', '0');
        if (isfield(h, 'solver'))
            solver = getfield(h, 'solver');
            if strcmp(solver, 'discrete(no continuous states)');
                set_param('pient9', 'Solver', 'FixedStepDiscrete');
            elseif strcmp(solver, 'ode5(Dormand-Prince)');
                set_param('pient9', 'Solver', 'ode5');
            elseif strcmp(solver, 'ode4(=Runge-Kutta)');
                set_param('pient9', 'Solver', 'ode4');
            elseif strcmp(solver, 'ode3(Bugaki-Shampine)');
                set_param('pient9', 'Solver', 'ode3');
            elseif strcmp(solver, 'ode2(Heun)');
                set_param('pient9', 'Solver', 'ode2');
            elseif strcmp(solver, 'ode1(Euler)');
                set_param('pient9', 'Solver', 'ode1');
            end
        end
    end
else % Variable step solver
    set_param('pient9', 'Fixedstep', '0');
    set_param('pient9', 'InitialStep', 'fstep');
    set_param('pient9', 'MaxStep', 'auto');
    if (isfield(h, 'solver'))
        solver = getfield(h, 'solver');
        if strcmp(solver, 'discrete(no continuous states)');

- 109 -
solver = 'VariableStepDiscrete';
elseif strcmp(solver, 'ode45[Dormand-Prince]');
    set_param('picnt9', 'Solver', 'ode45');
elseif strcmp(solver, 'ode23[Runge-Kutta]');
    set_param('picnt9', 'Solver', 'ode23');
end
end
end

% Here the appropriate parameters are sent to the simulink model
set_param('picnt9/PID Controller', 'P', 'pgain');
set_param('picnt9/PID Controller', 'I', 'igain');
set_param('picnt9/PID Controller', 'D', 'dgain');
set_param('picnt9', 'stoptime', 'simend');
set_param('picnt9/Step', 'After', 'simstepsize');
sim('picnt9', [], options); % Model is then executed

save('results.mat', 'time', 'response', 'ip', 'control'); % save results to a mat file

% Graph the results
f = figure;
plot(time, ip, time, response);
grid;
if (isfield(h, 'select'))
    plant = getfield(h, 'select');
if strcmp(plant, 'Twin Tank';
    title('Twin Tank Response');
elseif strcmp(plant, 'Level and flow');
    title('Level & Flow Response');
else
    title('InkJet Printer Response');
end
Appendix B.

end

xlabel('time(t)');
ylabel('position');
close_system('picnt9', 1)

% Render jpeg and write to file.
drawnow;
s.GraphFileName = sprintf('%step1.jpeg', mlid);
wsprintjpeg(f, s.GraphFileName);

s.GraphFileName = sprintf('/icons/%step1.jpeg', mlid);

% Put name of graphic file into HTML template file.
templatefile = which('results.html');
rs = htmlrep(s, templatefile);% returns the graphic

B.3. Experiment M-File

realtime.m

function rs = realtime(h)
% RS = REALTIME(H) accepts variables passed to it from
% the webpage parameters.html. It converts these variables
% to numeric values and passes them to a Simulink model.
% This model is then executed in realtime..
% Handle H is the structure created by matweb.
% Author(s): Dave Hamilton
% CIT
Appendix B.

% Insure the m file can see all the appropriate RTI files
to avoid compiler issues
addpath c:\dspace\config;
addpath c:\dspace\ds1104;
addpath c:\dspace\ds1104\rtkernel;
addpath c:\dspace\exe;
addpath c:\dspace\matlab\rti1104\m;
addpath c:\dspace\matlab\rti1104\c;
addpath c:\dspace\matlab\rti1104\t1c;
addpath c:\dspace\matlab\rti1104\sfcn;
addpath c:\Ds\matlab\local;
addpath c:\dspace\matlab\dssimulink;
addpath c:\dspace\matlab\mlib;
addpath c:\dspace\matlab\dssimulink;
addpath c:\MATLAB701\toolbox\rtw;
addpath c:\MATLAB701\toolbox\rtw\rtw;

% Get unique identifier (to form file name)
mlid = getfield(h, 'mlid');

% Set directory path for storage of graphic files.
cd(h.mldir);
% Cleanup jpegs older than 1 hour.
wscleanup('ml*tep1.jpeg',1);

cd c:\matlab701\work\wsdemos; % ensure we are in web directory
open picnt9e; % open the Simulink model
% Take the parameters in from the webpage and convert
% them to numeric values and assign them to the correct workspace.
prop= str2double(h.pgain);
assignin('base','pgain',prop);
int = str2double(h.igain);
assignin('base','igain',int);
deriv = str2double(h.dgain);
assignin('base','dgain',deriv);
endtime = str2double(h.simend);
assignin('base','simend',endtime);
samp = str2double(h.fstep);
assignin('base','fstep',samp);
stepsize = (str2double(h.simstepsize)/10);
assignin('base','simstepsize',stepsize);

% Pass the variables to Simulink
set_param('pient9e/PID Controller', 'P','pgain');
set_param('pient9e/PID Controller', 'I', 'igain');
set_param('pient9e/PID Controller', 'D', 'dgain');
set_param('pient9e', 'stoptime', 'simend');
set_param('pient9e/Step', 'After', 'simstepsize');
set_param('pient9e', 'BlockReductionOpt', 'off');
set_param('pient9e', 'OptimizeBlockIOStorage', 'off');
close_system('pient9e', 1); % save and close the model

% Build the Simulink model. It is downloaded into the dSPACE card
% with the simulation state set to stop.
rtwbuild('pient9e');

% Now we use the MLIB/MTRACE commands to run the program
% and collect the data.
mlib('SelectBoard', 'ds1104'); % using a DS1104 DAC
var_names = {'simState';...
'Model Root/Step/Out1'; % Pick out the signals we need
'Model Root/Scope/ln1'; ...
'currentTime'; ...
'Model Root/Step/After'; ...
'Model Root/Saturation/Out1'};
var = mlib('GetT 쉽게Variable', var_names);
mlib('Write', var(1), 'Data', 0); % just be sure simulation is stopped

% set options here
mlib('Set', 'Trigger', 'on' ,
    'TriggerLevel', 0.1 ,
    'TriggerVariable', var(4),
    'TraceVars', var ,
    'NumSamples', 9000, % 9 seconds
    'Delay', 0);

mlib('Write', var(1), 'Data', 2); % Start the program
mlib('StartCapture'); % Start capturing data

while mlib('CaptureState')~=0, end % wait until capture time is done

out_data = mlib('FetchData'); % pull out data correctly
input = out_data(2,:);
output = out_data(3,:);
control = out_data(6,:);
time = out_data(4,:);

% save data in appropriate manner
save results -v6 input output time control;
save results.ascii.mat ascii input output time control;
% send print carriage home
mlib('Write', var(1), 'Data', 0);
mlib('Write', var(5), 'Data', 0);
pause(0.3);
mlib('Write', var(5), 'Data', 0.7);
mclear; % clear data for next run
exit; % clear data for next run
quit;
Appendix C: Survey Forms

C.1 Results of Web Based Survey:

The following results are from the management interface of the web survey software. They show the actual responses from the students.

### Results: DLX Skills assessment

**Student Consent:** The results of this evaluation form may be published; in that event your consent is required. Your participation will remain anonymous. If you agree to have the details of your questionnaire published as part of a research project then please tick the following boxes:

<table>
<thead>
<tr>
<th>Option</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>I agree to participate in this project.</td>
<td>3 (3)</td>
</tr>
<tr>
<td></td>
<td>75%</td>
</tr>
<tr>
<td>I agree to these results being used for education and research provided my anonymity is maintained.</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>50%</td>
</tr>
<tr>
<td>I understand that I am under no obligation to take part in this process, and non participation will have no bearing on any treatment I now receive or will in the future.</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>50%</td>
</tr>
<tr>
<td>I understand that this is a not-for-profit process and I cannot expect any benefit to accrue to me.</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>50%</td>
</tr>
</tbody>
</table>

Base: 3 out of 4 people answered this question

1. Having some experience in a professional engineering environment how would you rate the relevance of the PBL learning experience to professional practice?

<table>
<thead>
<tr>
<th>Option</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Choose One</td>
<td>(4)</td>
</tr>
<tr>
<td>Very Relevant</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>50%</td>
</tr>
<tr>
<td>2.</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td></td>
</tr>
<tr>
<td>Relevant</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>25%</td>
</tr>
<tr>
<td>5.</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>25%</td>
</tr>
<tr>
<td>6.</td>
<td></td>
</tr>
<tr>
<td>Not Relevant</td>
<td></td>
</tr>
</tbody>
</table>
2. Using the inkjet printer developed my problem solving abilities.  

<table>
<thead>
<tr>
<th>Option</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(4)</td>
</tr>
<tr>
<td>Choose One</td>
<td></td>
</tr>
<tr>
<td>A great deal</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>50%</td>
</tr>
<tr>
<td>3.</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>50%</td>
</tr>
<tr>
<td>A little</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td></td>
</tr>
<tr>
<td>Not at all</td>
<td></td>
</tr>
</tbody>
</table>

Base: 4 out of 4 people answered this question

3. How important were these skills within your cooperative work placement environment?

<table>
<thead>
<tr>
<th>Option</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(4)</td>
</tr>
<tr>
<td>Choose One</td>
<td></td>
</tr>
<tr>
<td>Very Important</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>25%</td>
</tr>
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<td>3.</td>
<td>2</td>
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<td></td>
<td>50%</td>
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<tr>
<td>Important</td>
<td></td>
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<tr>
<td>5.</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>25%</td>
</tr>
<tr>
<td>6.</td>
<td></td>
</tr>
<tr>
<td>Not Important</td>
<td></td>
</tr>
</tbody>
</table>

Base: 4 out of 4 people answered this question
4. Undergoing the course improved my teamworking skills

<table>
<thead>
<tr>
<th>Option:</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(4)</td>
</tr>
<tr>
<td><strong>Choose One</strong></td>
<td></td>
</tr>
<tr>
<td>Improved a lot</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td></td>
</tr>
<tr>
<td>Improved a little</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>25%</td>
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<td></td>
<td></td>
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<td>1</td>
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<td>25%</td>
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<td></td>
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</tr>
<tr>
<td>6.</td>
<td></td>
</tr>
<tr>
<td>Not at all</td>
<td></td>
</tr>
</tbody>
</table>

Base: 4 out of 4 people answered this question

5. How important were these skills within your cooperative work placement environment?

<table>
<thead>
<tr>
<th>Option:</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(4)</td>
</tr>
<tr>
<td><strong>Choose One</strong></td>
<td></td>
</tr>
<tr>
<td>Very Important</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>50%</td>
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<td></td>
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<tr>
<td>2.</td>
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<tr>
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<td>Important</td>
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</tr>
<tr>
<td>6.</td>
<td></td>
</tr>
<tr>
<td>Not Important</td>
<td></td>
</tr>
</tbody>
</table>

Base: 4 out of 4 people answered this question
6. Undertaking the course improved my ability to learn independently on my own.

<table>
<thead>
<tr>
<th>Option:</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(4)</td>
</tr>
<tr>
<td><strong>Choose One</strong></td>
<td></td>
</tr>
<tr>
<td>Improved a lot</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>3</td>
</tr>
<tr>
<td>75%</td>
<td></td>
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<tr>
<td>3.</td>
<td>1</td>
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<tr>
<td>25%</td>
<td></td>
</tr>
<tr>
<td>Improved a little</td>
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<tr>
<td>5.</td>
<td></td>
</tr>
<tr>
<td>25%</td>
<td></td>
</tr>
<tr>
<td>Not at all</td>
<td></td>
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<tr>
<td>6.</td>
<td></td>
</tr>
</tbody>
</table>

Base: 4 out of 4 people answered this question

7. How important were these skills within your cooperative work placement environment?

<table>
<thead>
<tr>
<th>Option:</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(4)</td>
</tr>
<tr>
<td><strong>Choose one</strong></td>
<td></td>
</tr>
<tr>
<td>Very Important</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>2</td>
</tr>
<tr>
<td>50%</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>2</td>
</tr>
<tr>
<td>50%</td>
<td></td>
</tr>
<tr>
<td>Important</td>
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<tr>
<td>5.</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td></td>
</tr>
<tr>
<td>Not Important</td>
<td></td>
</tr>
</tbody>
</table>

Base: 4 out of 4 people answered this question
8. How satisfied are you that the PBL experience had a positive effect on your cooperative work experience?  

<table>
<thead>
<tr>
<th>Option</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(4)</td>
</tr>
<tr>
<td>Choose One</td>
<td></td>
</tr>
<tr>
<td>Very Satisfied</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>25%</td>
</tr>
<tr>
<td>3.</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>50%</td>
</tr>
<tr>
<td>Satisfied</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>25%</td>
</tr>
<tr>
<td>Not satisfied</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td></td>
</tr>
</tbody>
</table>

Base: 4 out of 4 people answered this question

9. What additional skills do you believe undertaking the PBL module gave you that were of benefit during your cooperative work placement?  

<table>
<thead>
<tr>
<th>Option:</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(3)</td>
</tr>
<tr>
<td>Comments:</td>
<td></td>
</tr>
<tr>
<td>The skills that I have undertaken have been the aptitude to obtain information of a product looking for it on internet or in manuals. Communication and report written skills. The skill of communicating with team members while works need to get done based on each member. Since in a team work, I can't garenteen everyone is getting the work done on time or with good quality, in that case I needed to talk to them individually before report to manager. If the team members still not paying much attention on their work should get done, I would report to manager then.</td>
<td></td>
</tr>
</tbody>
</table>

Base: 3 out of 4 people answered this question
10. How would you change the PBL course to improve it and/or make it more relevant to cooperative work placement experience?

<table>
<thead>
<tr>
<th>Option:</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(3)</td>
</tr>
</tbody>
</table>

**Comments:**
The PBL course could be centered in the products of the companies where we are going to do our placement, because the printer is very different than the work at Analog Devices for example. Have more time to it in a day to make it like a real work place. One hour classes are not long enough maybe need more time to get used to this approach solving problem, because it takes time to thinking and learning by ourself.

Base: 3 out of 4 people answered this question

11. Additional Comments: Large free-text box

<table>
<thead>
<tr>
<th>Option:</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(2)</td>
</tr>
</tbody>
</table>

**Comments:**
I have learned a lot of thing with you, and I have learned to work in a team, and this is very important today. The idea of PBL is good, but since I have been talking to some of classmates who has no experience in Embedded control, they seemed not quite too sure what they have learned. I think this is the problem of PBL.

Base: 2 out of 4 people answered this question
C.2 Initial feedback form given to students:

### Student Course Assessment Form

1. Comparing teamwork with individual learning (or working by yourself), which do you prefer?

<table>
<thead>
<tr>
<th>Prefer teamwork alone</th>
<th>no preference</th>
<th>prefer to work</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Do you think that the problem-based learning course has improved your ability to work effectively in a team?

<table>
<thead>
<tr>
<th>Definitely yes!</th>
<th>No improvement</th>
<th>Definitely no!</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Do you think that you would learn more through the problem based learning method or the traditional lecturing method?

<table>
<thead>
<tr>
<th>Learn more with PBL</th>
<th>No difference</th>
<th>Learn More with traditional</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Did the problem based learning part of the course require you to do additional work compared with traditional lectures?

<table>
<thead>
<tr>
<th>I did a lot more work</th>
<th>I did the same amount of work</th>
<th>I did a lot less work</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5. The problem based learning course developed my thinking skills (problem solving, analysis, etc) ...

A great deal □ □ □ □ □ □ □
a little □ □ □ □ □ □ □
Not at all □ □ □ □ □ □ □

6. Comparing the printer equipment with the normal laboratory equipment (tank) did you

Prefer working with the Printer? □ □ □ □ □ □ □
No preference □ □ □ □ □ □ □
Prefer working with the tank? □ □ □ □ □ □ □

7. How satisfied were you with the resources (handouts, time, equipment) that were made available?

Very Satisfied □ □ □ □ □ □ □
Dissatisfied □ □ □ □ □ □ □
OK □ □ □ □ □ □ □
Very □ □ □ □ □ □ □

8. Overall, how would you rate your satisfaction with the problem based learning experience?

Very Satisfied □ □ □ □ □ □ □
Its OK □ □ □ □ □ □ □
Very dissatisfied □ □ □ □ □ □ □

9. Given a choice, would you prefer if the Control Systems Course was taught exclusively through problem based learning or through traditional lectures?

Definitely problem based learning □ □ □ □ □ □ □
mixture of both □ □ □ □ □ □ □
Definitely lectures □ □ □ □ □ □ □
Appendix C.

10. Would you like to see problem based learning introduced into other subjects within the Department of Electronic Engineering?

Definitely yes! □ □ □ □ □ □ □
No preference □ □ □ □ □ □ □
Definitely No! □ □ □ □ □ □ □

11. What did you like about the problem based learning experience?

[Blank space]

12. What did you dislike about the problem based learning experience?

[Blank space]

13. How do you think the problem based learning course could be improved?

[Blank space]
14. Any additional comments?

Thank you for taking the time to fill out this form. Your feedback is greatly appreciated and will be used to improve the course for future students.

Tom O'Mahony & David Hamilton, Feb. 2007
References


(last accessed 20/7/2009)


[40] Online Collaborative Learning in Higher Education, 


[72] Problem-Based Learning directory http://feedback.bton.ac.uk/pbl/pbldirectory/index.php (last accessed 23/03/2009)


[80] http://www engr.psu.edu/cde/projects/Felder_Talk.htm (last accessed 26/05/2009)


References.

(last accessed 02/08/2009)


[149] dSPACE http://www.dspaceinc.com
(last accessed 21/06/2009)

[150] Modelling dc motor:
http://www.engin.umich.edu/group/ctm/examples/motor/motor.html
(last accessed 03/08/2009)


[152] MATLAB System Identification Toolbox:
http://www.mathworks.com/products/sysid
(last Accessed 21/7/2009)


[154] Internal Model Control: http://lorien.ncl.ac.uk/ming/robust/imc.pdf
(last accessed 29/07/2009)
[155] MATLAB Control System Toolbox:  
http://www.mathworks.com/products/control/  
(last accessed 21/7/2009)


[161] Blackboard Academic Suite:  
http://www.blackboard.com/ (last accessed 28/07/2009)


[163] Microchip  
http://www.microchip.com/stellent/idcplg?IdcService=SS_GET_PAGE&nodeId=64  
(last accessed 28/07/2009)