Student perceptions of a pilot-scale, problem based learning module in engineering.

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***Abstract*— Over the past three years the authors have focused on introducing student centred learning into a third year engineering module by integrating lectures and practical work in a studio format and introduced a significant amount of active learning through simulation and computer-aided design. Reflection on these changes indicate that while they have a positive effect on student motivation and learning, students ability to solve open-ended problems, learn independently and work effectively in teams is poor. To address these problems the authors devised a short pilot-scale blended problem and project based learning (P^2BL) course component. Since our students have little or no experience of the problem-based learning methodology, the initial weeks are heavily scaffolded in an attempt to minimize frustration and maximize learning. In this paper the authors briefly describe the problem based learning component and focus on student perceptions of this innovation. Student perceptions were determined through a Rikert-scale questionnaire and examined via face-to-face interviews. These perceptions are combined with the instructor's observations and reflections on the P^2BL based learning course component. Of particular note is the fact that overall the students responded positively to the P^2BL format and students were unanimous in recommending that P^2BL be adopted in other modules within the department. From the instructor's perspective, it was noted that students experienced considerable difficulty translating basic knowledge obtained earlier in the module to the open-ended problem used in the P^2BL component. Clearly, the course as it exists, does not effectively teach students some of the fundamental concepts of this discipline and this is a cause for concern. Future work will examine whether additional open-ended problems can address this concern.**

***Keywords* – Project-based learning, control education, experiential learning.**

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1. Introduction

Since the 1960's, engineering education has been dominated by mathematical and scientific principles, much to the detriment of the transferable skills, such as team working and problem solving. Increasingly, this paradigm of education is being criticised as failing to develop key skills that are required by professional engineers (Felder, 1984; Wulf, 2002; National Academy of Engineering, 2005). The most frequently cited skills are communication, teamwork, lifelong learning and an awareness of ethical responsibilities (Wang et al, 2005). In an Irish context, the call for change is been led on two fronts. From an academic perspective, the National Qualification Authority of Ireland (NQAI) and the Higher Education and Training Awards Council (HETAC) have been to the forefront of promoting change. HETAC require that engineering graduates 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 are aware of the responsibilities associated with working in and contributing to a multi-disciplinary team (HETAC, 2005). From a professional, practising engineering perspective the accreditation body in the Republic of Ireland, Engineers Ireland, have formulated six programme outcomes 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 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"* (Engineers Ireland, 2007). Whilst the onus is placed on the academic community to implement these criteria, and most would agree that these are desirable attributes for a graduate engineer, the question remains of how best to achieve this desire, and it remains largely unanswered. To this end the instructional models problem-based learning (PBL) and project-based learning (PjBL) are blended by the authors and used to deliver one component of a control systems module at the Department of Electronic Engineering, Cork Institute of Technology.

2. PBL AND ENGINEERING EDUCATION

2.1 Problem Based Learning

Problem based learning (PBL) is defined by Norman and Schmidt (1992), 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.1). 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 (Canavan, 2008). General strengths of PBL as an instructional technique are that students attend class more regularly, they express more interest in course material, and they retain information better and transfer their learning more effectively (Amador et al., 2006).

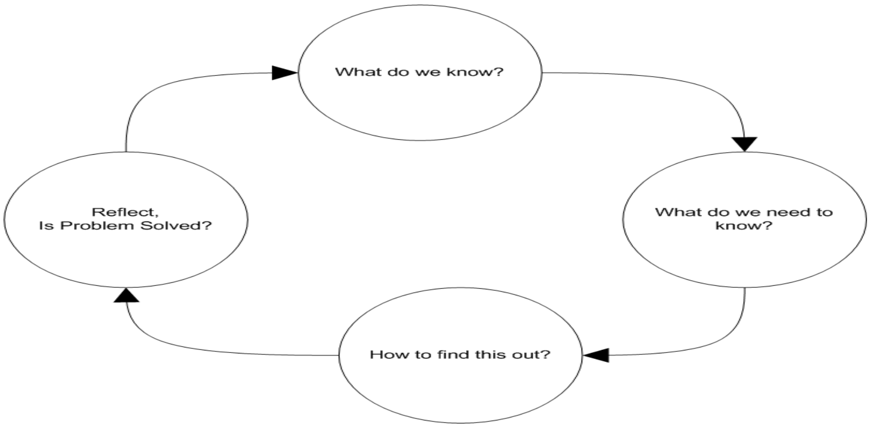

Fig.1. The PBL Process

2.2 Project Based Learning

In contrast to PBL, project based learning (PjBL) has its roots in engineering and science faculties. Most definitions of PjBL include elements of cooperative work, prolonged active or experiential learning, the development of key skills such as project management and the use of authentic projects (Perrenet et al., 2000). In contrast to problem based learning, project based learning is usually directly supported by taught courses. 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. Typically, both instructional techniques aim to develop a broad set of transferable skills, including the ability to solve problems; to work in teams and to learn independently. This leads us to the question of which methodology is most suitable for engineering education and in particular will best produce the desired aims of both the academic and professional bodies in an engineering context?

PBL was developed by medical faculties and while it has been transferred to a variety of educational settings, including engineering, its widest adoption continues to be in medicine as it closely mirrors the professional requirements of medical practitioners. A number of authors note that PBL is not so closely aligned with engineering professional practice (Perrenet et al., 2000; Mills & Treagust, 2003) which is typified by large-scale projects that persist for some time, that requires multidisciplinary teamwork and requires a compromise between a number 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. Furthermore, in medicine, knowledge is often classified as being encyclopaedic and thus suited to PBL while in engineering knowledge tends to be hierarchically constructed. 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 (Mills & Treagust, 2003) while at the same time allowing 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 and tasks. Furthermore, PjBL can accommodate both the hierarchical knowledge structure typified in engineering and the conservative nature of engineering faculties through the taught courses that accompany PjBL. However, despite the fact that PjBL is widely adopted in engineering education, its effectiveness as an instruction technique remains an open question. Most evaluations focus on student perceptions via questionnaires and the main results are positive statements with respect to key skills, particularly communication and teamwork, and increased student motivation (Clarke & Hake, 1997; Mills & Treagust, 2003; Lima et al., 2007).

3. MOTIVATION

The Department of Electronic Engineering at Cork Institute of Technology 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 3. The average expected student workload for the module is seven hours per week, five of which are timetabled as contact hours. The course is delivered in a studio based format where theory and practice are delivered simultaneously and a high degree of active learning, though simulation and practical experiments, is incorporated. The use of computer aided design software, MATLAB, is an integral part of the course. The rational for this is to mimic professional practice where the use of such software would be widespread and to reduce the burden on students by enabling them to avoid performing protracted mathematical operations by hand and focus on the key concepts and techniques of the discipline. The terminal examination, which corresponds to 70% of the assessment mark, is an open-book computer assisted exam that uses the same CAD software. This module works well in that students enjoy the module and have commented positively on the active learning component, noting in particular that it is stimulating and helps maintain their interest during the timetabled periods. Course evaluations supported these observations.

However, it was felt that there was room for improvement. For example, the course cohort for the academic year 2007-08 were involved in the production of a promotional video for electronic engineering. During this production, students were recorded applying their learning in the laboratory and were asked how this learning would translate to the real world. The authors were surprised to observe that the cohort had real difficulty answering this question and, while realistic examples were frequently cited in the module, it became apparent that the module needed to be concretised. Furthermore, the authors felt that while students were frequently given problems to solve, these problems tended to be a little formulaic, with a single solution and the problem solving process was all too frequently led by the instructor. Finally, the authors were keen to introduce both teamwork and independent learning as these are also key skills that appear in both the Engineers Ireland list of programme outcomes and the NQAI programme descriptor.

To achieve these aims the authors have considered transforming the course to a combined project and problem based learning pedagogy. To evaluate the possible impact of this transformation, to develop the requisite teaching skills and to evaluate student attitudes it seemed prudent to implement the pedagogy on a small scale initially. Thus, a short trial was conducted during the last three weeks of the module in the academic year 2007 - 2008. In keeping with the problem and project based learning philosophy, and the desire to concretise the course, an authentic project was developed. This is briefly described in the following section while section 5 describes the pedagogical environment.

4. PROJECT SELECTION

The project requirements are that it should be an authentic electronic engineering system that required control, it needed to be sufficiently complex to present a number of possible solutions (open-ended problem), and require extended teamwork over a three week period and yet be sufficiently simple to be solved by applying the basic principles of the discipline (this is the students first course in control). Ideally, it should be both visual and commonly experienced to help concretise the subject matter. Consequently, the authors spent a number of months researching and evaluating a number of different possibilities prior to electing to use a standard desktop inkjet printer. In addition to satisfying all of the above criteria, this device also turned out to be a very cost effective one, as a simple campus-wide email request was rewarded with a plethora of old inkjet printers. A number of them were the Hewlett Packard DeskJet model, which are a common sight in many office environments and represents a familiar piece of everyday equipment to the students (see Fig. 2).

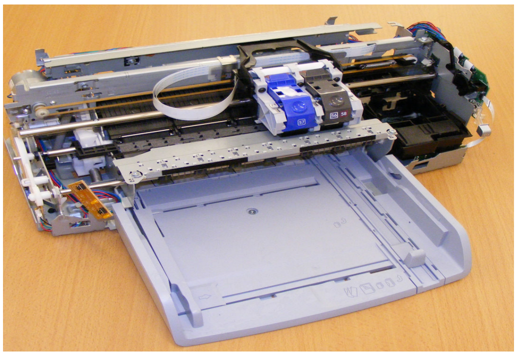

Fig. 2. HP Deskjet Printer with plastic cover removed

Basically, an inkjet printer works by jetting tiny bursts of ink onto a page. For it to work well the location and timing of these ink bursts must be carefully controlled. This is achieved through two control systems, one that regulates the position of the print carriage (the device that holds the printer cartridges and print head) and a second that controls how the paper is spooled through the printer (paper form feed). The design challenge for the print carriage, for example, is to maximise the speed at which it moves across the page (thereby increasing the number of words per minute printed) while at the same time ensuring that each letter is printed correctly (no blotches or trails of ink on the page). Other objectives, at different times, are to accurately position the printer cartridge when, for example, it needs to be cleaned or the ink cartridge needs to be replaced. Similar requirements can be specified for the paper form feed. A more detailed overview is presented by Harriman (2005) who discusses several of the major challenges faced by the Hewlett-Packard Company in designing inkjet printers and in particular the constraints on the control systems are highlighted.

The problem presented to the students was then to develop a control strategy to control the print carriage. The design was to be performed on a PC using dedicated CAD software and rapid development tools. The design was interface to the printer via dedicated data acquisition tools. These tools allow signals generated on the PC to be sent to the printer and signals from the printer to be viewed and manipulated on the PC. An advantage of the inkjet printer is that the existing controller is easy to bypass and the requisite signals are all easy to access. Furthermore, all of the signals are low-power and do not present a health or safety hazard. A hybrid problem & project based learning (P^2BL) approach was felt to be the best possible approach in order to fulfil the requirements of ensuring that the learning outcomes are achieved and the differences in learning styles of the students are catered for. While the authors believe that PjBL is very suited to engineering, in their experience they believe that it lacks a formal problem solving process. Combining the well-defined process from PBL with PjBL, results in a hybrid which has the best of both worlds.

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5. PEDAGOGY

5.1 Scaffolding

The student cohort involved in this pilot was small, comprising six people and consisting of an equal mix of nationalities (Irish, Spanish and Chinese), of which two were female. The pilot scheme ran over a timeframe of three weeks, and consisted of a weekly student workload of seven hours per week. To support the introduction of P^2BL into the course the traditional laboratory environment was converted to a learning space as described by Crawley et al (2007). 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 and presentations. In keeping with the PBL 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. In the cooperative learning literature, the work of Johnson et al. (1998) is frequently cited as a particularly good resource for devising a supportive environment. In this work, the authors define five tenets of effective cooperative learning. These tenets are mutual interdependence, individual accountability, interpersonal skills, promotive interaction and group processing. These tenets were used to design the pedagogical environment to support the P^2BL 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 (1995): *"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 (1999) argue that the degree of self-dependent learning is not always developed to the optimum level in PBL practice. Effective educational systems should gradually offer more control over the process of learning by students and Thomas (2000) 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 and Greening (1998) suggests that these scaffolds be focused in the non-discipline areas (such as group dynamics, metacognition, etc.). The process was therefore initiated with a workshop to inform students of the rationale for the change, to present the PBL strategy (Fig. 1), to provide them with resources for PBL, to explore the concept of effective teamwork, and to inform them of their responsibilities within a team. The students were then presented with the following scenario:

You have just graduated with an honours degree in Electronic Engineering from CIT and have been hired by Hewlett-Packard Ireland as a design engineer. HP is in the process of designing a new desktop INKJET PRINTER and you have been assigned to the group responsible for this project. Your new boss calls the graduates into his office. "I want to find out what you're capable off" she says. "I want you, as a team, to design the control system for the print cartridge carriage for our new inkjet printer. You have until the 25th of February''

To ease the transition to P^2BL students were provided with extra resources, especially links to suitable websites and articles to act as 'signposts' along the P^2BL road. The teaching philosophy was that the number of supplied resources would reduce week by week as the students developed competence and confidence in their own abilities to learn independently. Students were also provided with resources to assist with the project planning and teamwork process e.g. a provisional project timetable (Fig. 3), a detailed timetable for week one (Fig. 4), a job sheet (Fig. 5) that acts as a record of achievement and learning and also as a form of muddy card (Mosteller, 1989) and template forms for agendas and minutes of meetings. It was repeatedly emphasised to the students that the problem solving process was the critical aspect and a working final solution was of secondary importance. The team leader and recorder were elected by the student team and they agreed a schedule of works and meeting times.

Provisional project plan			
	Summary description	Deliverable	Deadline
Work-package 1: familiarization	Become familiar with INKJET printer technology, particularly the control technology for the inkjet print cartridge carriage loop.	10-15 min group presentation on INKJET printer technology, focusing on control loop for print cartridge carriage.	Thursday 14th Feb at 9:00
Work-package 2: interfacing	Interface the printer to the rapid development environment used for controller prototyping based on dSPACE DS1102 controller board	Demonstrate that the printer has been correctly interfaced by sending out signal to move the print cartridge carriage and reading the sensor to measure how far it has moved.	Thursday 21st Feb at 9:00
Work-package 3: controller design	Design a controller to control the print cartridge carriage. The control objectives are to move the cartridge as quickly as possible without overshoot.	Demonstration of working controller.	Monday 25th?

Fig.3. Provisional Timetable

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

Fig.4. Detailed Timetable

As mentioned previously, the learning environment was carefully planned and monitored to encourage effective teamwork. A number of measures were introduced to encourage mutual interdependence, as recommended by Johnson & Johnson (1999). These measures included positive goal interdependence (a sufficiently complex problem/project was developed so that students would perceive that the task was too large for any one of them to complete independently), positive reward (marks were clearly allocated for effective teamwork), positive resource independence (students were allocated different resources on different aspects of the printer and only by pooling those resources and the knowledge elicited from them could the project be completed) and positive role interdependence (leader, recorder, checker).

Allocating different resources to different students also helped to achieve individual accountability as students perceived that they were required to complete individual work. In week one this consisted of allocating different learning resources to each student e.g. the Harriman (2005) paper, a paper on dc motors, websites for incremental encoders, etc. Utilising the 'jigsaw' method (Aronson, et al., 1978), the students broke up into sub teams and become familiar with the different printer technologies. Subsequently, they regrouped and disseminated the information that they had gathered to the team as a whole. During this process peer pressure helped to ensure individual accountability. A clearly allocated portion of the marks (1/3) reinforced this idea. Accountability was then measured through a group presentation, where any member of the team may be asked to deliver any portion of the presentation. A follow-up group question and answer session also helped to measure accountability.

The initial workshop defined the key skills that are required for effective team-work and the subsequent three weeks provided students with the opportunities to practice those skills (interpersonal skills). Throughout the process students engaged in face-to-face promotive interaction by discussing ideas and problem solving approaches and 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. To assist this process an assessment rubric 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.

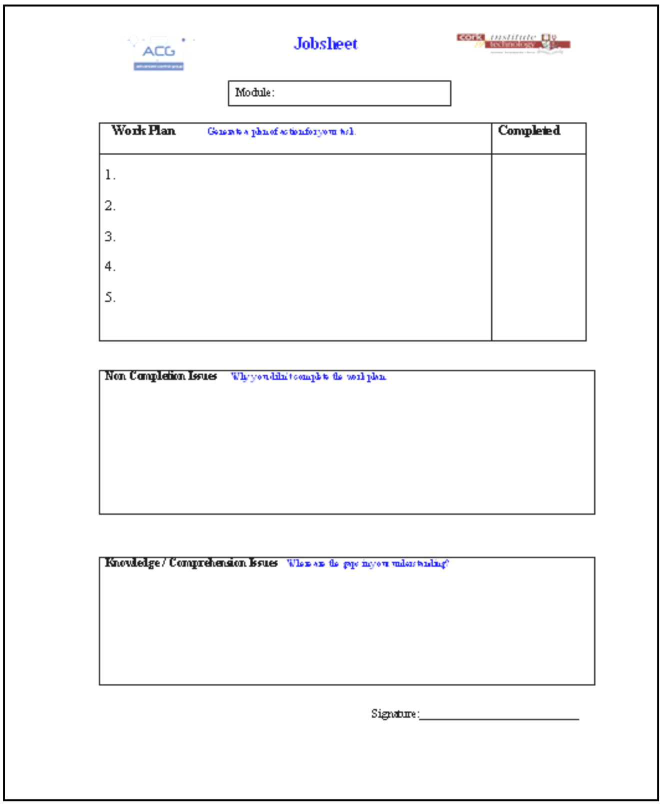

Fig. 5. Jobsheet

In week two, the number of supplied resources was reduced. Students did not receive a detailed timetable for that week and instead were required to develop their own action plan for this and subsequent weeks and also to allocate tasks to individuals or sub-groups within the team. Project planning is critical skill for professional engineers and this phased approach was designed to (i) illustrate what a project plan should look like and (ii) then provide students with the opportunity to develop their own. The team elected to split into pairs with each pair having separate responsibilities; one pair learned about the software environment that supported the PC-printer interface, a second pair worked on interfacing the printer motor to the PC while the third pair worked on interfacing the printer sensor (an incremental encoder) to the PC. This was a logical division of the work required at this stage, and in keeping with the positive task interdependence concept all three tasks needed to be successfully completed to progress to the next stage. During this phase, a workshop on the computer software was provided to support the pair working on this particular element of the problem. Accountability was encouraged during this period through the practical demonstration of the hardware and software, and all students were required to be able to demonstrate any component of the process.

In week three the only student support provided was access to the teaching staff for general questions. The students had a broad outline of what was required from the original project timetable (Fig. 3) and were required to interpret this and revise it, develop a detailed plan for the week and again allocate work to individuals or sub-groups. It was hoped that the students would, at this stage, have received sufficient guidance to work in a truly cooperative manner. The team were required to present their work to the teaching staff and defend their work in a question and answer session.

5.2 Evaluation

Evaluating the effectiveness of pedagogical change is notoriously difficult as there are so many contributory factors and variables. Studies comparing project-based learning to conventional instruction have yielded results similar to those obtained for problem-based learning, including significant positive effects on problem-solving skills, conceptual understanding, and attitudes to learning, and comparable or better student performance on tests of content knowledge (Thomas, 2000; Mills & Treagust, 2003). In general, course evaluations, questionnaires, interviews and summative assessment techniques are used to assess the success of the process relative, usually, to the more traditional methods of teaching. In this pilot-study, the effectiveness of the P^2BL component was evaluated using a short questionnaire and by conducting a face to face interview with each student. 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. 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 questions based on a seven point Rikert scale. The questionnaire concluded with four 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?

Question	**Average**
Q1 (1=prefer team work 7= prefer work alone)	2.33
Q2 (1=yes teamwork improved 7=no)	2.00
Q3 (1=learned more with PBL; 7=learned more traditional)	1.83
Q4 (1=more work; 7=less work)	2.33
Q5 (1=thinking skills developed; 7=no change)	2.83
Q6 (1=prefer printer; 7=prefer tank)	4.00
Q7 (1=satisfied with resources; 7 very dissatisfied)	2.83
Q8 (1=overall very satisfied; 7=dissatisfied)	2.50
Q9 (1=prefer PBL for control systems; 7=prefer traditional)	3.83
Q10 (1=more PBL within department; 7=definitely no)	1.83

Fig.6. Results of Questionnaire

All six students completed and returned the questionnaire. Prior to commenting on the results of this questionnaire and the interviews it must be repeated that the student numbers participating in this module are low and therefore 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 6. As mentioned previously, students were asked to respond to each question based on a 7 point Rikert scale where broadly speaking, 1 on the scale corresponds to strongly positive and 7 strongly negative. Examining the results it is apparent that the students had strongly positive experiences in the areas of teamworking, they felt that they learned more using the PBL approach and that they would like to see PBL introduced into more modules within the Department of Electronic Engineering. The students were positive about the PBL process itself, believed that their thinking skills had improved somewhat and that the PBL 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% PBL students unanimously selected the mid-point of the scale corresponding to ‘a mixture of both’. The other question sought to evaluate student’s preferences for laboratory equipment: inkjet printer or traditional equipment, and 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.

6. INSTRUCTOR AND STUDENT REFLECTIONS

The authors were particularly keen to investigate 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% PBL module. To this end, the authors decided to interview the students and in the process also obtain a more personalised perception of the P^2BL process. In addition, the authors noted that during the P^2BL process the students appeared to experience problems transferring prior knowledge to the new problem. The interviews also attempted to elucidate this issue. As the students were due to sit terminal exams immediately after the P^2BL component the authors elected 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: Q1 What did you think of the PBL experience?; Q2 Have you any suggestions for improvements?; Q3 How did you find the experience of working in a team?; Q4 What do you think was the most important thing that you learnt?; Q5 The questionnaire indicated that most of you would like a mixture of PBL and the traditional approach. Why do you think that is? Q6 Would you like to see PBL in other modules? Q7 Would you have a preference between the printer equipment and the tank (traditional) equipment?; Q8 Why do you think you adopted ad-hoc approaches in the final week to design the controller?; Q9 What did you think of the resources that were provided?; Q10 Did PBL require a greater effort from you compared with the traditional approach? Q11. What skills do you think you developed during the PBL component? The main results are summarised below and compared with the instructors reflections.

A central tone of the interviews is the positive attitude of the students towards P^2BL. 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 some day you weren't that…if you weren't that interested, like, you would have to stay in the class like, but with that [PBL] 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 P^2BL 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 its 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 P^2BL process also caused anxiety for some students. One of the principal causes was the dilemma highlighted by Schanck and Cleave (1995) of how to learn by solving problems if you don't know how to solve problems:

"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 P^2BL process it was clear to the instructors that the students were poorly prepared for teamwork and found it difficult to communicate, particularly difficult to organise and manage projects such as the P^2BL 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 P^2BL 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 P^2BL 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 P^2BL 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]. In general, the authors concur with these reflections. Students exceeded instructor's expectations in their ability to learn independently (as measured by their understanding of inkjet printer technology) and their ability to solve technical problems (as measured by their ability to interface the printer to the PC). In general, students completed these stages ahead of schedule.

During the P^2BL component, the instructors noticed that 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 PBL process and the interviews was a terminal exam and this might suggest that 'revising' for the terminal exam helped in this regard and that 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"*. On reflection, the instructors would agree that 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. The instructors also accept that it is feasible that students might choose ON/OFF control as it is the simplest option given the timeframe, but 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 'learnt'. In our thinking, this particular issue clearly illustrates the shortcomings of the traditional experimental method where the student completed the exercise almost by rote and does not achieve a deep understanding of the underlying principles. The consequent was that students were unable to apply the techniques to a new scenario, and this supports a rationale for introducing more PBL into the curriculum. The authors postulate that if the curriculum was reversed, and students began with an extended version of this PBL component, where they design their ad-hoc controller, analyse its limitations (from a design and performance perspective) and then iteratively investigate superior alternatives (proportional control then proportional plus integral) students would be more likely to succeed when given a new scenario. This hypothesis remains to be verified.

As outlined in section 2, one of the objectives of the P^{2}BL 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. This was a disappointing result for the instructors. 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 looked more complicated and was more complicated and this complexity contributed to the neutral response obtained in the survey. However, this complexity might be a good thing, as it forced 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 P^{2}BL process.

The interviews also help illuminate the neutral response to the 100% PBL 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*" in the theory such as the controller design methodology and the computer aided design tools used or they "*would have sunk''*. However, given that the students didn't actually apply much of the theory 'learnt' prior to the P^{2}BL component the authors don't

accept this argument - rather the contrary, that the course would be improved by introducing P^2BL right from the start. It is presumed that the students response is based totally on their single experience and that they found it difficult to imagine an alternative format but that if they experienced P^2BL first (or 100% P^2BL course) then this opinion might differ. Students also believed that such a radical change might pose problems for them. Student one, for example, 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:
"Its 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"

It is interesting to note that the survey data and throughout all of the interviews students consistently and explicitly mention how the P^2BL 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 P^2BL process, student 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 is a pleasant albeit unexpected result. The authors are, however, surprised that students did not reflect more on the technical learning achieved. This is perhaps due to the short time frame, in this time perhaps students could only focus on the transferable skills. This is understandable given the students own appreciation of their deficiencies in these areas at the beginning of the process and their relative familiarity with receiving new technical information across all subjects. These reflections would appear to be a clear testament of the potential that P^2BL possesses for developing these skills.

An interesting common thread prevailed, unsolicited throughout all of the interviews, namely students perceived, that the P^2BL process mimics how they have experienced or 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 PBL 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 PBL 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 P^2BL learning process is clearly highly motivating and perhaps accounts, to some extent, for the very positive reactions towards the learning experience.

7. CONCLUSIONS & FUTURE WORK

Over the past number of years the authors have been incrementally introducing student centred learning into a third year engineering module by integrating lectures and practical work in a studio format and introduced a significant amount of active learning through simulation and computer-aided design. These changes have had a positive effect on student motivation and learning, but in the authors opinion the students' ability to solve open-ended problems, learn independently and work effectively in teams was poor. To this end a hybrid problem and project based learning module was designed conforming 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 P^2BL). This particular course component has the benefits of providing an authentic problem which is cost effective and provides control challenges that are suitable for an introductory control course. Though the complete exercise entailed an additional workload for the authors the fact that the main aims of evolving teamwork and problem solving skills, and promoting independent learning were achieved made it a most worthwhile exercise and has bolstered the authors' belief of its appropriateness within engineering education.

Based on their experience of running this pilot the authors are keen to maintain and, possibly extend, the P^2BL component. The difficulty that students experienced with transferring core principles and techniques of the discipline illustrates the shortcomings of traditional experimental methods where the student does not achieve a deep understanding of the process and perhaps this is where P^2BL 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. The authors feel that implementing this module as 100% PBL is a natural progression with the caveat that providing substantial 'just in time' scaffolding in the form of workshops and mini lectures is essential and would in fact accurately mirror professional practice.

The authors believe that the P^2BL component can be integrated into a blended learning (Reichlmayer, 2005) environment with other subjects in the curriculum, for example, in computer systems students study microcontrollers such as the Microchip® PIC family. To date, there has been little integration across the curriculum between control systems and computer systems within our 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 a 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. And while we are convinced of the merits of the P^2BL approach, many of our brethren within the faculty remain to be convinced. That may yet prove to be the biggest obstacle to achieving an integrated curriculum in Electronic Engineering.

Further work needs to be done with the printer in order to teach more advanced control concepts to this and other classes. The suitability of the printer to achieve these aims is yet to be determined, but the authors are in the process of determining other pieces of everyday equipment that may achieve those aims as well. The authors also hope to implement some form of remote laboratory (Aktan, et al, 1996) that can be used within the P^2BL framework. The aspiration is that the students will be able to access the equipment 24/7 and be able to try out for example their own controller designs during times when physical access to the equipment is restricted.

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9. REFERENCES

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