A FORAY INTO P^2BL IN A CONTROL SYSTEMS COURSE

David Hamilton[ϕ], Tom O'Mahony[¤]

Advanced Control Group
Department of Electronic Engineering,
Cork Institute of Technology,
IRELAND
E-mail: [ϕ]dave.hamilton@cit.ie, ¤tom.omahony@cit.ie

Abstract: Project- and problem-based learning are recommended instructional models that develop students capabilities to solve problems, work in teams and learn independently. This paper presents a course component, developed by the authors, in which the students are presented with an authentic problem and a blended project and problem based learning instructional model is used to develop these transferable skills. The component also integrates international best practice from the field of education. A number of techniques were used to evaluate the course and the results indicate that students perceived that the component developed their ability to work in teams and are very open to similar components being introduced into additional modules. However, the authors noted that students experienced considerable difficulty translating prior knowledge to an unfamiliar scenario and this prompts (as yet unanswered) questions about the effectiveness of traditional teaching models.

Keywords: Control Education, Problem and Project Based Learning, Inkjet printer.

1. INTRODUCTION

In the recent past engineering education has been dominated by mathematical and scientific principles to the detriment of professional and transferable skills. As a result there have been many calls for change, based on many independent reviews in many different countries (Felder, 1984; Wulf, 2002; National Academy of Engineering, 2005). To some extent these calls still reverberate in the wild. For example, the report by AC Nielsen Research Services (2000) documented employer dissatisfaction in Australia with a number of graduate transferable skills including oral communication, problem solving, interpersonal, business, and creativity. While in the USA in 2002, the then president of the National Academy of Engineering posed and answered the question "how different is engineering education today from when I was a student, so many years ago. The answer is, except that we do not teach drafting and surveying anymore, not much!" (Wulf, 2002).

Increasingly, engineering accreditation bodies are insisting that the skills demanded by industry be shown to have been practised and assessed. For example, the accreditation body in the Republic of Ireland, Engineers Ireland (2007), 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 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". While most academics would probably agree that these are desirable attributes for a graduate, the question of how these attributes are best achieved is largely unanswered.

Felder and Brent (2003) provide some guidelines, albeit with respect to the USA's Accreditation Board for Engineering and Technology (ABET) criteria. Of relevance to this paper, Felder and Brent (2003) state that once "problem-based learning has been adopted in a course, very little additional work must be done to address all of Outcomes 3a–3k". In contrast, in the UK, the Quality Assurance Agency (2000) engineering benchmark statements for both Honours BEng and MEng awards make reference to the value of project work as a mechanism for developing key skills in engineering graduates.

In this paper the instructional models problem-based learning (PBL) and project-based learning (PjBL) are blended and used to deliver one component of a control systems course at the Department of Electronic Engineering, Cork Institute of Technology. The main academic aims of this component are to improve student's ability to (i) solve engineering problems (ii) work in teams and (iii) learn independently while concretising (Bernstein, 1999) the control experience. This is the first instance of the combined PBL and PjBL models being used in this course and one of the objectives of this trial run is to evaluate the effectiveness and student's perceptions of the instructional techniques. The component is run over three weeks with an expected student workload of seven hours per week. The contribution of this paper is to present the pedagogical approach and to evaluate its effectiveness for a control systems course. The paper includes a detailed description of the problem scenario that students were presented with, in addition to the assessment strategy used. The authors believe that this contribution is significant for two reasons (i) to our knowledge the literature is devoid of accounts of problem-based learning being used in a control course (ii) the problem being studied can easily be replicated in other third-level institutes.

In the following, section 2 outlines the key features of problem and project-based learning and the motivation for a hybrid model while section 3 describes the control problem presented to the students. Section 4 describes the organisation of the PBL component and the assessment strategy is outlined in section 5. Section 6 evaluates the pedagogical approach. Finally, in section 7 some conclusions and further work are detailed.

2. P^{2}BL

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). While it was initially developed at M^{c}Master University in Canada to help medical students to become practitioners of medicine, it has since been implemented in numerous educational settings, over a variety of educational institutions, at different levels, and in different disciplines. The literature suggests that the strengths of PBL as an instructional technique are that students attend class more regularly, they express more interest in course material, they retain information better and transfer their learning more effectively (Amador, Miles & Peters, 2006).

While PBL was traditionally associated with medicine, project based learning (PjBL) has its roots in engineering and science faculties. Both methodologies share a number of commonalities: both are student-focused; students work on authentic tasks; they use authentic assessment artifacts; 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 (fig 1) is

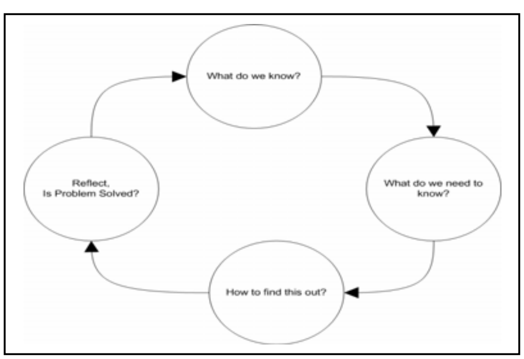


Fig. 1 The PBL Process

often more important than the actual product. 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.

A strength of the project-based learning approach is its close alignment with the activities that graduates are likely to engage in industry. Integral to the project is the requirement to solve a variety of problems. However, the process by which these problems could be resolved is not explicitly defined. This process is the defining element of problem-based learning, hence the marriage of problem and project-based learning (P^{2}BL). Another argument for supporting a hybrid approach is that the traditional 'medical school' PBL approach is not particularly suited to the current undergraduate engineering higher education environment. For example, Allen *et al*, (1996) notes that students in the medical school setting have particular characteristics i.e they are "intellectually mature and highly motivated, and have the opportunity to work in small groups with an assigned faculty tutor". PjBL offers the potential to address a deficit in motivation, especially if the end-goal is a tangible, stimulating, product.

3. THE CONTROL PROBLEM

The control systems course is part of a four year Bachelor of Engineering (Honours) in Electronic Engineering offered by Cork Institute of Technology. Control Systems is a required module in the third year of this degree. Students taking this module typically have completed Laplace, Fourier and Z-Transforms in a mathematics course and have previous, albeit limited, exposure to basic linear systems concepts. The course content is typical and 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 delivery is a little less typical and, influenced by Atherton (2006) the course relies on the use of MATLAB/Simulink to achieve the course learning outcomes and to relieve the heavy mathematical content. Thus all lectures are studio-based (facilitated by small numbers < 20) and normally constitute a short lecture to introduce a concept followed by a period of active learning where students investigate a topic by completing a set of exercises using MATLAB and/or Simulink. Students usually work alone or in pairs. The terminal exam is an individual open-book computer aided assessment.
While the course generally receives very positive feedback from students, the authors believe that the exercises that the students tackle are too structured, that the lecturer/tutor solves too many of the problems, that students have few opportunities to practice real team-work, and that too much information is given to the students. In addition, practical work (e.g. designing an ON/OFF controller, PI controller) is performed on typical laboratory apparatus e.g. the position control of an Amira® dc motor is examined. While this is undoubtedly

beneficial, the authors believe that students have difficulties relating to these systems because they are 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.

A number of different apparatus were investigated, with the view to developing a course component that would address some of these issues, before settling on an inkjet printer as a suitable vehicle to drive learning. This in itself is not new, Van de Molengraft *et al*, (2005) document the use of an inkjet printer as a laboratory experiment in a control course. In the view of these authors, 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. 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. However, tight control is not necessarily trivial as a diverse set of constraints act on the print carriage and print media servo designs including physical, economic and computational constraints. These real world issues are documented by Harriman (2005) in the context of the major challenges faced by the Hewlett-Packard Company in designing inkjet printers.

Of significant interest to this project (which has no budget!) was the fact that the chosen apparatus was very cost effective. 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. 2). 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.

4. PEDAGOGICAL STRUCTURE

The first 18 weeks of the control systems course were taught as described in section 3. In week 19, the students were organised into teams of six and given the following scenario:

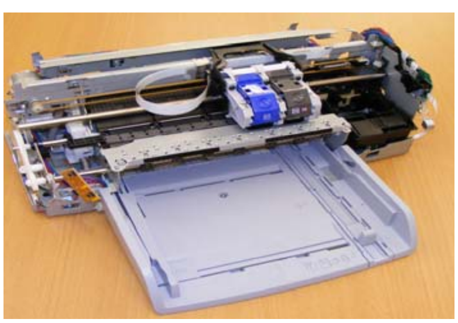


Fig.2. HP Inkjet Printer

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 "so I have a little problem in mind for you." "I want you, as a team, to design the control system for the print cartridge carriage for our new inkjet printer." "You have until 25th of February''

Since these students have 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). In week one the students would be provided with extra resources, including conference papers and links to suitable articles and websites to act as 'signposts' on the P^2BL road. A workshop on effective teamwork was run and students were provided with additional resources on teamwork. A detailed plan of action for this week was also supplied 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 forms relating to meetings (agenda and minutes in particular), and job sheet 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 (Mosteller, 1989). Teams elected their own co-ordinator and recorder and agreed a schedule of work and meeting times.

Table. 1. The timetable for the project:

Week	Action/Deliverable
1	Become familiar with INKJET printer technology, particularly the control technology for the inkjet print cartridge carriage loop. Deliverable: 10 min group presentation
2	Interface the printer to the rapid development environment used for controller prototyping based on dSPACE DS1102 controller board Deliverable: Demo of working interface
3	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

The literature on collaborative learning is clear that group success is predicated upon two factors: positive interdependence and individual accountability (Johnson, *et al*, 1998). During week one, positive interdependence was achieved by ensuring that teams 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 groups appointed individuals to read and report back on those resources. In addition, one group also had members research 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. Individual accountability was achieved through the assessment process as outlined in the next section.

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 (www.dspace.ltd.uk). This week was less structured and required that the teams 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, a workshop was timetabled, and two students from each group 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 groups were encouraged to subdivide into a minimum of three groups of two and address software, encoder interface and motor interface in parallel. Once the pair of students that participated in the software workshop, were confident that they could use the software they split and assisted each of the other groups in configuring the software and acquiring data that demonstrated the working interface.

Minimal student support was provided during week three – aside from encouraging and questioning the group and individual process and answering general questions. The group'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 student teams can, and did, choose a wide variety of paths including controlling position or velocity; type of controller ON/OFF, P, PI; and design methodology, trial-and-error, modelling followed by trial-and-error design in MATLAB/Simulink or a root-locus design using the MATLAB rltool function. Positive interdependence was encouraged by insisting that groups sub-divide 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 each team to support this activity.

Table 2. Assessment Methods

Learning Outcome	Assessment Methods
Group	
Team work	Observation, Presentations Demonstration, Jobsheets, Project Outcome, Documentation.
Individual	
Independent Learning	Self Assessment, Jobsheets, Presentation & Demonstration
Problem Solving	Self Assessment, Jobsheets, Demonstration, Observation.

5. ASSESSMENT METHODS

Current best practice in teaching and learning recognises 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 (Biggs 2003). For the learner, the assessment process is often critical as for many learners (e.g. strategic learners) it drives the learning process. Biggs' constructive alignment philosophy implies that the following three learning outcomes need to be assessed: LO1 – students will be able to learn independently; LO2 – students will be able to work effectively in a team and LO3 – students will be able to solve technical open-ended problems. In keeping with the philosophy of student-centred learning it was felt that the student should assume some responsibility for the assessment. Therefore the assessment consisted of two components a tutor mark and student self-assessment mark. The tutors' evaluation was based on observation of the group and group products as outlined in table 2 and the documentation including agenda and minutes of meetings and individual job-sheets. A self assessment rubric was designed to assist the student self-assessment process. The rubric was designed to evaluate both teamworking skills and technical competencies. Each week students were required to submit a ~half-page self-assessment report based on the rubric for that week.

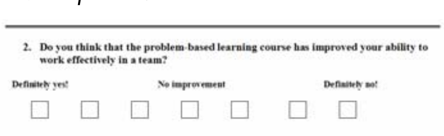
It is important to ensure that the individual's performance within the group is accurately reflected in their overall grade, and so the authors have dedicated two thirds of the assessment grade for individual work and one third for the group work element. In addition to this continuous assessment, one element of the terminal open-book examination (one question out of six) will pertain to the P^2BL course component.

Section 4 mentioned individual accountability as a concept that is important for the success of group work. In the context of this component this is reinforced through the assessment methodology. Thus, for example, with the group presentations students are advised and warned that the order in which they will be asked to deliver the presentation will be chosen at random at the beginning of the presentation. Thus there is an onus on each member to do their own work and learn about what the others did. Likewise, during the demonstrations, individuals were asked to explain the work that they did and to discuss how it contributed to the group effort.

6. EVALUATING P^{2}BL

Evaluating the effectiveness of pedagogical change is notoriously difficult as there are so many contributory factors and variables. In problem-based learning, course evaluations, questionnaires, interviews and summative assessment techniques are frequently used to assess the success of the pedagogy relative to alternatives. In this commentary, the effectiveness of the P^{2}BL component was evaluated using a short questionnaire, comparison of continuous assessment (CA) marks and tutor reflections. The questionnaire evaluated students perceptions of the problem-based learning methodology, the equipment used, resources provided, learning achieved (problem solving and teamwork) and the effort applied. Students were explicitly asked if they would prefer the control systems course 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 course within the Department of Electronic Engineering. Students were asked to evaluate their perceptions to each of these ten questions based on a seven point Rikert scale. An example is illustrated in Fig.3. 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?

Prior to commenting on the results of this questionnaire it must be noted that the student numbers participating in this course are low and therefore a statistical analysis is unreliable. Notwithstanding this, the questionnaire revealed some interesting data. All of the students felt very strongly that the PBL component improved their ability to work in a team, that they learned a lot more via the PBL approach, and that they would like to see PBL introduced into more courses within the Department of Electronic Engineering. In response to the question '*Given a choice, would you prefer if the Control Systems Course was taught exclusively through problem based learning or through traditional lectures?*' students unanimously selected the mid-point of the scale corresponding to '*a mixture of both*'. There was much wider distribution


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

Definitely yes! No improvement Definitely no!

☐ ☐ ☐ ☐ ☐ ☐ ☐

Fig. 3. Sample from Student Questionnaire

in the student responses to the remaining questions, and through the average was generally positive it is difficult, and probably not wise, to extract further meaning. The only exception was the response to question six which sought to evaluate student's preferences for laboratory equipment: inkjet printer or traditional equipment, which elicited an average neutral response. 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. Or perhaps this objective was achieved but students found it more difficult to work with as a simple interface was not provided. There is some anecdotal evidence to support the latter. For example, in the open questions one student commented "appreciated real world" while another "confusing", yet another wanted to look at "something simpler than a printer".

Observing the student groups as they worked through the PBL process it was clear to the authors that the students were poorly prepared for teamwork and found it difficult to organise and manage the project. While this component demonstrated how a collaborative project could be managed, and students perceived that they learnt a lot about teamwork, given the short time frame over which the component was run, these students will probably need a lot more real team-work experience to develop effective team-work skills. The authors noticed that all teams experienced real difficulty transferring prior knowledge to an unfamiliar scenario. All of the students in this course had designed and implemented an ON/OFF controller and a proportional controller for standard laboratory apparatus (to control level in a single tank apparatus, or speed control for a dc motor) and, at a later stage in the course had experienced a formal design procedure (obtain model, verify model, design PI controller, test PI controller, implement) using the same equipment. Yet, faced with the new scenario, the groups invariably reverted to ad-hoc techniques for control (mostly variations of ON/OFF) and were at a loss to explain the resulting performance! On the other hand, students exceeded expectations in other areas namely their understanding of the inkjet printer technology and their ability to interface the printer to the PC. In general, students completed these stages ahead of schedule.

7. CONCLUSIONS AND FURTHER WORK.

The success of this pilot P^{2}BL scheme, and in particular student perceptions of the methodology, has bolstered the authors' belief of its appropriateness within engineering education. 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. The students involved believed that the problem-based learning component developed their ability to work in a team, expressed mixed feelings regarding its effect on their thinking skills, expressed a preference for a mixture of P^{2}BL and 'traditional' lectures and were very open to additional modules incorporating P^2BL elements. In designing the course component, the authors have endeavoured to adhere 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).

Based on their experience of running this pilot the authors are keen to maintain and, possibly extend, the PBL component. However, this does require re-thinking and re-planning the control systems course. To accommodate the three week PBL pilot all of the material on the root-locus and designing simple PI controllers via the 'rltool' in MATLAB was removed, in additional to some of the material on sampled data systems. More PBL implies more sacrifices elsewhere! More worryingly, however, for these educators was the difficulty that students experienced with transferring core knowledge. It had been 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? However, it would seem that this concept is being lost, perhaps in the quagmire that is stability, settling times, Nyquist diagrams, Bode plots and all the other concepts that are squashed into the course. 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 PI?

The PBL component can easily be extended to include control of the paper feed mechanism in addition to the print cartridge carriage. These two control loops could be tackled serially or in parallel and, through the latter, further reinforce the positive interdependence concept. The authors believe that the PBL 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 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. And while we are convinced of the merits of the PBL 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.

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