Seeding Enquiry-Based Learning in Electrical and Electronic Engineering: Case Study 1 – Optoelectronics

Norman J. Powell[1], Anthony R. Peaker [2], William S. Truscott [3], Peter J. Hicks [4], Brian Canavan [5]

Abstract - **Enquiry-Based Learning (EBL) was developed in the third-year, Electrical and Electronic Engineering (EEE) module Optoelectronic Devices and Systems. Problem-Based Learning (PBL) is an instance of EBL, where the students' enquiry into a topic is triggered by an initial problem or scenario. This module begins with a PBL exercise, which covers display devices. The students are asked to imagine that they are a small company that is about to develop a new large screen High Definition Television (HDTV) consumer product for the market in a few years. This links enquiry into existing and emerging display technologies with the specification and standards for HDTV. It also requires the students to project market trends and technological advances into the near future. Key decisions in the design of the scenario, consideration of the learning environment and the form of assessment are described, emphasising flexibility in approach and sensitivity to the context of this development.**

This development is in the second year of its delivery. The results of an integrative evaluation, drawing on questionnaires, participant observation, student focus groups and discussions with staff, will be presented. The varying experiences of three groups will be presented, highlighting the impact of both internal and external factors.

Index Terms – Electronic Engineering, Enquiry-Based Learning (EBL), Optoelectronics, Problem-Based Learning (PBL).

INTRODUCTION

The development of professional and personal skills in engineering students is becoming increasingly important. A recent survey of employers, conducted by the IET (Institution for Engineering and Technology) [1], highlighted a mismatch between the skills required by electronic engineers and the skills that graduates possessed. This finding is in line with similar studies and engineering education reviews in both America and Australia [2]. PBL is an instance of EBL [3], where the students' enquiry into a topic is triggered by an initial problem or scenario. The students following in this enquiry engage in the subject matter at a much deeper level, whilst gaining professional, personal and life-long learning skills in a process integrated with their core subject learning [4].

This paper and its companion paper (Case Study 2 – Robotics) report on some of the teaching and learning developments that arose at the University of Manchester, from a collaborative PBL initiative with University College London and the University of Bristol, supported by the IET [1] and HEFCE (Higher Education Funding Council for England). In Manchester, PBL has been introduced into three third-year units, in the areas of VLSI design [5], Optoelectronics and Robotics, and also as part of the second-year tutorial system as a preparation for a team project [6].

This paper describes the context of the module, and the *implementation* of a PBL exercise into it. It then describes the *evaluation* of the PBL exercise drawing out the experience of three groups of students. There then follows a *discussion* of the issues arising from this experience.

IMPLEMENTATION

Context

Optoelectronics Devices and Systems is an optional, 10-credit, third-year, second-semester module delivered through lectures with problem-solving tutorials delivered towards the end of the module as preparation for the examination. The contact time for the module is two 50-minute sessions per week. The summative exam represents 75% of the module. The remaining 25% of the module is taken up by a written assignment. The module is divided into two main sections: display technologies and communication systems. The former is a descriptive review and the latter a more quantitative treatment of the science and technology, representing the major portion of the module.

Scenario

In many respects the components for a PBL were already in place: the more descriptive display technologies theme combined with the individual report. Display technologies provided an accessible and motivating topic for enquiry, since television is a very tangible component of people's everyday experience. Also the diversity of display technologies, the development of new technologies and the

[1] Norman J. Powell, Centre for Excellence in Enquiry-Based Learning, University of Manchester, United Kingdom, norman.powell@manchester.ac.uk
[2] Anthony R. Peaker, School of Electronics and Electrical Engineering, University of Manchester, United Kingdom, a.peaker@manchester.ac.uk
[3] William S. Truscott, School of Electronics and Electrical Engineering, University of Manchester, United Kingdom, w.truscott@manchester.ac.uk
[4] Peter J. Hicks, School of Electronics and Electrical Engineering, University of Manchester, United Kingdom, peter.hicks@manchester.ac.uk
[5] Brian Canavan, Robert Clark Centre for Technological Education, University of Glasgow, United Kingdom, b.canavan@elec.gla.ac.uk

introduction of new formats onto the market provide a stimulating and changing topic for enquiry.

The students were asked to imagine that they are a small company that is about to develop a new large screen HDTV consumer product for the market in a few years' time. This links the enquiry into the existing and emerging display technologies with the specification and standards for HDTV. It also requires the students to project market trends and technological advances into the near future.

Timing

This topic fits naturally at the beginning of the module, providing a lighter introductory topic before the more technical optical communications section. Placing the PBL exercise at the beginning of the module has the additional benefit of avoiding the peak workload times for the students which occur later in the semester, when they are likely to encounter coursework from other modules and be preoccupied by completing their third year projects.

A disadvantage, however, is that for the first couple of weeks of the module, students are still deciding which optional modules to select, so the size and make-up of the class are uncertain and fluctuates. This is mitigated partially by giving over the first two or three sessions to introductory talks on the module in general, displays specifically and PBL. The following four to five sessions, depending on the groups' progress, are given over to team meetings. The students are then given a further two weeks to write up an individual report on their research.

Resources

The lecture had in place a series of detailed notes as handouts for each component of the module. The first volume of these notes, covering the electromagnetic spectrum, colour perception and display technologies, were provided in the introductory lectures as a starting point for the enquiry. Students were also referred to the PBL, Information Searching and Group Working guides that they were provided with in their second year.

It was anticipated that the majority of resources would be accessed via the Internet, through searching technical databases, in the form of review articles from professional journals and technical reports from manufacturers. Students were given instruction on the use of technical databases at the end of the first team meeting.

Another resource that was offered to the students was the lecturer's expertise. He offered to provide explanation and clarification of anything that the students found difficult during their enquiries, on either an individual or group basis.

Learning Environment

This module was scheduled to take place in a raked lecture theatre. This was not considered conducive to group work, so a flat lecture theatre with movable desks was found for the first year of the team meetings. For the second year there was only one group, consequently team meetings could be convened in the lecturer's office.

Process

During the team meetings, the students in their groups:

- discussed their understanding of the scenario;
- shared their current knowledge and ideas on the topics involved;
- made decisions on how to address the scenario;
- identified what specific topics, or learning objectives, they needed to research in order to progress their enquiry;
- allocated who was going to investigate which topics;
- made arrangements for keeping in contact with each other between the scheduled facilitated sessions.

Between the team meetings the students would conduct their individual research on the topics allocated. The next team meeting would then begin with the students sharing the findings of their individual research with the group and discussing how their findings affect their perceptions of the scenario. Then the process of identifying learning outcomes and planning their group research was repeated and refined.

Facilitation

Two facilitators were present for these sessions. One facilitator was the lecturer, the other a non-specialist who also acted as a participant observer.

The lecturer began the team meetings with an outline of what he hoped they would achieve, outlining the process steps and types of decisions that should be made by the end of the meeting. This provided a clear sense of purpose and direction for the meeting, especially for groups that were more hesitant and uncertain about how to progress. During some parts of the meeting he absented himself from the room to allow less inhibited discussions, especially during the decision and allocation phases. At the close of the meeting he asked the group to summarise their decisions and intended directions of enquiry, providing feedback and encouragement. In the year when there were two groups this was a plenary session, allowing a cross-fertilisation of ideas between the groups.

Throughout the facilitation sessions, the lecturer was sensitive to the progress and coherence of the groups and provided appropriate levels of support and direction to ensure that the group progressed.

The non-expert facilitator adopted a less interventionist approach, observing and listening to the groups' discussion and making infrequent suggestions when they were felt appropriate.

Assessment

The PBL was assessed solely through an individual 2500 to 3500 word report, based on the groups' research. This being a substantial portion of a third-year module, the marking of a team product and mechanisms for assigning individual marks might have been contentious. The method chosen was seen as an appropriate low risk option for this level of course, where teamwork is not an explicit learning outcome.

Delivery

The PBL exercise was first delivered in the second semester of 2005-06 to 2 groups of 4 and 5 students. It was repeated in

the second semester of 2006-07 to a group of 10 students. Both cohorts contained a mixture of both home and foreign students. The apparent discrepancy in the group sizes will be explained below under *Focus Groups and Observations*.

EVALUATION OF THE PBL PROCESS

Methodology

An integrative evaluation [7] was conducted, drawing on questionnaires, assessment, participant observation, student focus groups and the reflections of staff, where the focus is on understanding the experience of the students engaged on the PBL exercise. The questionnaire data was collected for the first year cohort, observations and focus groups were conducted for both years of delivery.

Questionnaires

Given there were only a small number of students involved in this activity, these results should be taken as indicative only. Even substantive results may not be significant. However, the response rate is good (78%-89%), so the results can be taken as representative of these students.

The Study Process Questionnaire [8] measures the students' approaches to learning, whether deep or surface. On average the cohort came out as having a Deep Learning Attitude of 31.4 and a Surface Learning Attitude of 22.0. This is not significantly different from other second and third year groups ($F(3,62)=0.12$, $p=0.95$ & $F(3,62)=0.82$, $p=0.49$).

Confidence Logs [7] measuring the students' confidence on a five-point Likert scale against the intended learning outcomes for the PBL were collected pre and post the PBL exercise. The results are summarised in Table I. For all save the first learning outcome (image perception) there are increases in confidence. This first topic was discussed in the introductory lecture and notes, but did not form part of any of the groups' enquiries, so this is probably a fair reflection of their learning. The two topics that show a significant improvement with an independent *t*-test are the Cathode Ray Tube and Liquid Crystal Displays. Despite not being significant increases in confidence, there do appear to be substantive increases in confidence in most cases. Given that the number of students is low in this sample, a larger cohort may yield more significant results. However, a paired *t*-tests on six matched responses show no significant results.

TABLE I
CHANGE IN CONFIDENCE (1-5) FOR LEARNING OUTCOMES

	Learning Outcomes (abbreviated here)	Change in Confidence	Standard Deviation	Sig. p * ($p<0.05$)
1	Image Perception	-0.27	0.77	0.514
2	Cathode Ray Tube	1.11	0.97	*0.047
3	Liquid Crystal Display	1.21	0.94	*0.026
4	Moving Colour Image Quality	0.95	0.86	0.053
5	Projection Displays	0.89	1.05	0.125
6	Plasma Displays	1.00	1.04	0.085
7	Display Performance and Cost	0.79	1.09	0.187
8	Projected Market Share	1.04	1.27	0.139
Average for all Learning Outcomes		0.84	1.07	0.153

Notes: Independent *t*-test for 8 pre and 7 post responses out of a possible 9

The Learning Resource Questionnaire [9] measures the frequency of use and the usefulness of the resources used by the students. The results are summarised in Table II. The Internet followed by discussion with students come out as the most regularly used and useful resources. The high use and usefulness of discussion with students indicates that students are both using and valuing the group discussions. Students' own notes and their discussions with the tutor were also used sometimes and found useful, suggesting that the initial resources and the tutor's input were also valued. The limited use and value of textbooks and borrowed notes is also expected.

TABLE II
LEARNING RESOURCE QUESTIONNAIRE

Resources	Frequency of Use 1 – Did not use *to* 4 – Used Regularly	Usefulness 1 – Useless *to* 4 – Vital
Lectures	N/A	2.5
Textbooks	1.6	1.6
Own notes from lectures or labs	2.8	3.1
Borrowed notes	1.5	2.0
Discussion with tutors	2.5	3.1
Discussion with students	3.8	3.5
Internet	4.0	3.9
Other	2.4	2.2

Note: 8 responses out of a possible 9

The Perceptions to PBL questionnaire is a bespoke questionnaire generated for the IET PBL initiative, its results are summarised in Table III. From these results there is a very positive reaction to the PBL exercise, with the students: enjoying the exercise, wishing to learn this way again and general agreement to most of the statements, with the exception of mild disagreement to preferring to learn through conventional lectures.

TABLE III
PERCEPTIONS OF PBL QUESTIONNAIRE

Statement (slightly abbreviated here)	Agreement 1 – Disagree Strongly 5 – Agree Strongly
I like PBL	4.4
I learn more from PBL than lecture based courses	4.1
PBL takes more time than lecture based courses	3.8
I have to take more responsibility for my learning in PBL	4.1
I enjoy working in a group	4.0
I clearly understood the problem given to me	4.1
I easily understood what was required of me in answering the problem	3.6
I was happy with the level of support provided by staff during the PBL	4.1
I prefer to learn through conventional lectures	2.5
I would like to learn in this way again	4.3
PBL has made me better at knowing how to find and use information	3.8

Note: 8 responses out of a possible 9

Assessment

Comparing the results of the coursework assessment across the years (Table IV), including the year previous to the introduction of the PBL exercise, show consistent results for the two PBL years. However these appear to be substantively higher (9%) than the non-PBL coursework, however this is not statistically significant ($p=0.09$).

If this difference were to be substantiated, it could be that the additional support provided by the group meetings and the sharing of the research process amongst the team might be leading to an improved final report.

Comparing the paired coursework marks with the final examination marks for the 2005-06 cohort. These results are

summarised in Table V. There is a strong correlation (Pearson's correlation coefficient r= 0.84, p=0.18, N=7), this suggests that the assessment is 'fair', that is, the marks reflect ability. The average coursework mark is 5% lower than the exam mark, not statistically significant (p=0.17), this might suggest better performance in the exams and greater familiarity with this method of assessment.

TABLE IV
SUMMARY OF COURSEWORK MARKS ACROSS YEARS

Year	Mean	Standard Deviation	Number
2004-05 – No PBL	57	17	16
2005-06 – PBL	65	13	8
2006-07 – PBL	67	13	10
All 3 Years	62	15	35

TABLE V
PAIRED COMPARISON OF COURSEWORK AND EXAM MARKS FOR 2005-06

Assessment Component	Mean	Standard Deviation	Number
Coursework	65	14	7
Exam	70	15	7

Note: Summary for students with both a coursework and exam mark only

So far we have considered the assessment in terms of the marks that it has produced. The generally very high quality of the reports was reflected in the increased assessment marks. There is evidence in all the reports that the students have engaged in a process of research, have made appropriate selection of these findings and have demonstrated understanding of the display technologies and the demands of the market through reporting these in their own words.

What does differentiate the reports is not the underlying research or understanding of the devices, but the ability to integrate and synthesise this into a coherent report. The weaker reports show a less smooth integration of the ideas and an over-reliance on the words of the sources. An extreme example this year used substantial blocks of accredited text from source materials, the selection and structuring was appropriate but did not lead to a coherent report and missed an opportunity to demonstrate their own understanding of the subject.

Focus Groups and Observations

The participant observations and discussions from the focus groups will be combined here to form vignettes of the experiences of the three groups that engaged in the PBL exercise over its two years of delivery. It is interesting to reflect that all three groups were ostensibly provided with the same stimuli: scenario; facilitation and learning environment. However, factors both internal and external to the groups produce differing experiences. It seems to be an inevitable consequence of this more student-centred and collaborative approach to teaching and learning that these variations in experience will be more likely to occur. The group, its internal dynamics and ownership of the learning become a central part of the learning environment. The experiences of the group and its members also become more exposed.

Group A, 2005-06: This group of five students included a socially confident young man, who had been particularly impressed by the *learning pyramid* [10] (Figure 1), presented during the introduction to PBL briefing. Taking on board the point that the highest retention of knowledge came from teaching the subject and linking this with the sharing research findings stage of the PBL process, he concluded that to gain the most out of this exercise he should use this part of the meeting to 'teach' the other team members about his findings.

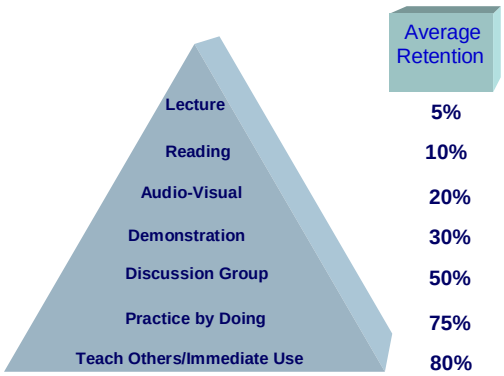

FIGURE 1
THE LEARNING PYRAMID [10]

This helped him in his mastery of the material, helped the other team members in understanding his findings and also set the tone for the group meetings to be a lively sharing of ideas.

The experience of this was also shaped by some of the other members of the group. By chance, though possibly a consequence of this group being formed from the back of the class, this group had a higher proportion of 'sporadic attenders'. It should be noted that their sporadic attendance continued throughout the taught part of the course, so was not a reflection of their attitude to PBL in particular. However, it was considered disruptive by the core active members of the group, especially near the end of the process when a group member who had been absent throughout most of the process reappeared and time was spent bringing her up-to-date.

This group, particularly the individual mentioned above, was very appreciative of this PBL experience and commended it as a way of learning. He would even select a module that used PBL over a conventionally taught module, if they were comparable in other ways.

Group B 2005-06: This group of 4 students, perhaps due to being formed from the front of the class, contained members who were more diligent in their attendance and engagement with the process. This group was made up, however, of more diffident students, who were perhaps less confident about sharing their ideas and contributing at length to a group discussion. Whereas in group A the primary mode of information sharing was through discussion, in this group information was shared principally through exchanging literature. This group created a website, where they posted documents and links to websites that they had found as a group resource. The process this group followed was to read and digest their shared findings prior to the meeting. In the meetings, any decisions would be made very quickly in a business-like, consensual manner, but with minimal discussion. They then found it difficult to use the rest of the

meeting constructively. The facilitator found it difficult to draw out any discussion or debate, since all the issues seemed to have already been agreed. The energy levels in these meetings were a lot lower than those of group A.

This group appreciated the intentions of the PBL exercise, especially the group work and collaborative aspects. Some of them had previously been out on placement and appreciated that the professional working environment consisted almost entirely of teamwork projects. However, they felt that this was really only a small 'taste' of PBL and thought that they would benefit from greater exposure to collaborative, team-based projects, citing the Embedded Systems Project, a team project that had recently been introduced into the second year as an example. This group, while supportive of the PBL exercise, felt that they had not had sufficient opportunity to gain the required skills to be successful and felt dissatisfaction that they were not using their team meetings productively. This suggests that more and different intervention from the facilitator would be beneficial to this group.

Group C 2006-07: If sporadic attendance was an issue for group A, it was more so for group C. With the exception of a few core group members, there seemed to be different students attending each meeting. New students were joining the module until near the end of the PBL exercise primarily because the course organisation allowed them to make their final decision on options well into the second semester. The group eventually consisted of ten students; however, at most six students ever attended a group meeting. Punctuality was also an issue for this group. Uncertainty about who was expected at a group meeting and when they would arrive did cut into the productive duration of the team meetings. This lack of continuity in group attendance and lack of commitment from the group members was frustrating for both the facilitators and the active members of the group. It also added to the inertia experienced at the beginning of the process.

This group appeared a lot more hesitant and unsure of themselves and how to proceed, and required a lot more direction and facilitation. For example, in the first team meeting, after a delayed start, the students were unsure how to address the problem and were reluctant to talk to each other. One student helpfully suggested spending some time individually thinking about the scenario and making notes, then they could compare notes later. However, this individual process went on a long time, despite prompting, leaving little time for group discussion. The meeting concluded with a general agreement that they would all research the topic generally and report back in the next meeting. This was probably the best decision that the group could make at this time. However, it did contrast groups A and B, who had already identified potential technologies that their companies might adopt and divided up specific topics for individual research by this stage.

Subsequent meetings were more productive, with group members bringing the results of their individual research and ideas generated prior to the discussion. This seemed to provide something more concrete to talk about and have confidence in sharing.

Despite these unpromising conditions, the group did manage to keep in contact electronically, principally through e-mail. There was discussion of using instant messaging, but it is unclear how much of this took place. The group managed to collect some interesting and useful resources and as described above produced generally high quality reports.

This group found the PBL exercise an interesting and different way of learning. They felt that they had learnt a lot about the subject and particularly commented on the group research process as being an efficient way of accessing a variety of information, which would have been impractical in the same time constraints as individuals. They noted that this was the first time they had done anything quite like this, despite having done the team projects in the second year, and they were still learning about the process as well as the content.

One student suggested providing a small PBL exercise as an introduction to the communications section of the module. This would allow the students to build up some background and context to the subject, which the students had ownership over, in which to locate the more quantitative aspects taught in the lectures and tutorials.

Two Chinese students commented that they felt at a disadvantage in relation to report writing, due to their language skills, preferring the numerical aspects of the course. They did however feel that one of the things that they were able to contribute to the group was finding sources of information in Chinese and essentially translating it to the group. This may be a useful means of empowering foreign language students in group discussions more generally, suggesting that they may be able to share resources with the group that it may not otherwise have access to. It should be noted that the Chinese students in this group were frequent attendees and preferred to focus on the technical rather than market aspects of the enquiry.

DISCUSSION

On the whole this appears to be a successful implementation of PBL, well received by the students who have worked well to produce high quality reports. During the process a number of issues arose concerning PBL as practised in this context. These will now be discussed.

Students' reactions to this style of learning are very different. Some students seem to take to it very naturally. Others find it difficult to understand what is expected and how best to engage with the process. This can be seen in the different reactions to the process in groups above. This may be a result of the students' preferred learning styles and their expectations of learning, based on their cultural backgrounds and educational experience. This also has an impact on the level of support and skills that the facilitators need to bring to the process.

It is perhaps naïve to expect students to spontaneously develop the requisite process skills by simply providing them with an opportunity to do a PBL exercise. Consideration is required of how to appropriately facilitate a group to develop these skills, without taking control of the process from the students.

In the lectured version of this course, the lecturer was able to cover a wider range of issues in the time. A consequence of moving to a PBL exercise has been to provide students the space to explore the topic more deeply at the expense of a narrowing of the topic.

It is of concern that during the PBL exercise and in their reports, the students avoided making numerical comparisons between specifications of the different technologies, falling back on vaguer more descriptive statements. When tables of comparisons were reported, they were frequently quoted completely from their sources. Considering the students' discipline it is important that they are able to approach new knowledge and make quantitative comparisons. Emphasising this aspect will be a focus of future years.

One of the issues that it was anticipated that PBL would address was the motivation and engagement of the students. This was not the principal motivation for applying PBL in this particular context, but was considered to be a potentially beneficial 'side-effect' in the PBL project as a whole. The active nature of PBL, requiring that students engage in the process for there to be any learning at all, and the additional motivation from authentic problems suggest *a priori* that PBL would improve the students' motivation.

Our experience here would suggest that, for the students already engaged and committed to the learning process, it did provide an engaging and rewarding learning experience. However, it did not seem to affect the attendance patterns of those less committed. It may be hoped that, for students whose engagement is in the balance, the PBL exercise would be an engaging influence; however, it is not clear if this occurred in this context.

There are a number of influences on attendance in this context: being at the beginning of an optional module, students are still deciding which modules to select; this is also a peak time for recruitment interviews; students faced with a coursework deadline may miss lectures to meet the deadline; and the learning culture of the cohort. It may be more productive to try to influence the learning culture earlier in students' academic careers, before expectations are set that lectures are optional and notes can be picked up after the event.

The lower risk approach to assessment reduced dependence on the coherence of the group. In this context, this was an advantage. However, it could be argued that it avoids the issue and a more team-based product might increase commitment to the team, or at least bring this issue of team commitment to the forefront.

CONCLUSIONS

This paper describes the implementation of PBL, a form of EBL, into a third-year, Optoelectronics module.

The results from the evaluation questionnaires suggest that the students learnt from the process, engaged in and valued research on the Internet and group discussions, and were generally well disposed to the process.

The reports that they produced from the process were of a high quality, demonstrating the required learning. There was concern, however, that they did not address topics in a quantitative manner, instead relying on description.

The experiences and reactions of the three groups involved, captured through participant observation and focus groups, were presented, drawing out principal differences in their experiences.

A number of issues that arose from this experience were briefly discussed, including: the different reactions of the students to the PBL process; a reduction in the breadth of coverage; a tendency for students to avoid quantitative comparisons; and student motivation and attendance.

We would like to conclude that introducing EBL into this module was a very worthwhile activity, which does bring with it its own challenges and issues.

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