Integration of Problem Based Learning To Produce Professional Engineers

Andrew Donnellan
Department of Electronic Engineering,
Institute of Technology Tallaght
Dublin 24, Ireland.
andrew.donnellan@ittdublin.ie

Abstract

Professional bodies require engineering programmes to deliver graduates with discipline specific knowledge and skills, as well as transferable ("softer") team, communication and lifelong learning skills, as defined in their accreditation handbooks. To deliver this spectrum of skills necessitates a paradigm shift in engineering education, as an exclusively traditional teacher driven approach to learning would not achieve these outcomes. The School of Engineering analysed the learning style preferences of students entering the school, discovering that the majority of students showed active, sensing, visual, and global preferences for learning. Motivated by the dual considerations of additional skills required by graduates and a suitable approach for the learning styles, it was decided to revise the software module in the penultimate year of an honours degree. Problem Based Learning (PBL) is a pedagogical approach that emphasises a student centred learning experience rather than the traditional teacher driven educational experience, and was adopted as a suitable approach by the School of Engineering..

This paper discusses how specific problems were designed to cover critical syllabus topics. The project and teams were designed as per best PBL practice. Conscious that assessment drives the learning experience, it was necessary to revise the assessment method. The paper discusses the guidelines given to the students, as well as the procedure for group selection. The paper shows how the PBL method improved the results as well as the level of understanding examined and demonstrated by the learners, as measured by benchmarking against the illustrative verbs for Bloom's Taxonomy's level of learning. The paper examines the learner's development of 'team' skills and discusses the challenges of this "reflecting while doing" approach and how the learners and learning facilitator coped with this learner driven experience. It finally proposes further features to be incorporated to enhance future learning.

Keywords : Problem based learning, Learning Styles, Professional engineer

A need for change

In the past professional bodies required engineering programmes to deliver graduates with discipline specific knowledge and skills. These skills include an ability to derive, apply, identify, analyse and solve engineering problems. It would also require design of systems and experiments as well as an ability to work effectively as an individual. These discipline specific skills may be achieved by traditional module delivery, but practitioners should explore if there is a more effective way.

However, today professional bodies require engineering programmes to deliver graduates with more than the discipline specific knowledge and skills. To become a professional engineer a graduate must have demonstrated various non-discipline specific abilities. These would include effective teamwork, a capacity for lifelong learning, and the ability to incorporate the responsibilities of the engineering profession towards people and the environment into their work. The graduate must also have shown an ability to communicate effectively with the engineering community and with society at large. The full list of requirements is defined in the professional association's accreditation handbook (Engineers Ireland, March 2007).

These skills can not be achieved by exclusively traditional module delivery. In the traditional engineering programmes the teaching of good communication, the ability to self-direct, and other transferable skills have been predominately developed through the year long individual projects. Professional bodies desire that these non-discipline specific skills permeate the programme by incorporation into a range of modules, rather than be addressed in a single module. Delivering this spectrum of skills across a range of modules necessitates a paradigm shift in engineering programmes. This progressive school engages with pedagogical enhancements, wishing to constantly improve the learning environment.

In addition to these global influences there were local issues that motivated a reflection regarding the learning on the programme. Learning styles in general and specifically the learning style preferences of engineers have been examined and classified under 4 domains (Felder, 1988). The 4 domains are (i) sensing and intuitive, (ii) visual and verbal, (iii) active and reflective and (iv) sequential and global.

Felder provides his 'Index of Learning Styles'(ILS), which is a self-scoring questionnaire for assessing preferences in the four dimensions. There have been papers which have examined the reliability and validity of this test and the authors concluded that the ILS meets standard acceptability criteria for an instrument of its type (Felder, 2005). It is acknowledged that "learning style profiles suggest behavioural tendencies rather than being infallible predictors of behaviour" and that "learning style preferences can be affected by a student's educational experience" (Felder, 2005) but the group's learning style profile gives an indication of possible strengths tendencies within the group.

In a desire to accommodate the needs of its specific students, the School of Engineering analysed the learning styles of first years entering the school (Cranley, 2005). This analysis showed that the majority of students were active, sensing, visual, global learners. The study would suggest that the traditional "talk and chalk" approach was not best suited to the learners on this programme. The traditional approach is directed more towards verbal learners. This was further highlighted by the fact that from the 2004 group there was a strong or extremely strong visual and active learning style amongst the students who failed (Cranley, 2005). These studies were performed on first year students, but used as an indicator of learning style preference of the penultimate year students taking this module, as the student group had shown this preference when they were in first year and the profile has been similar over a number of years.

Module Design

Motivated by the dual considerations of additional skills required by graduates and a suitable approach for the learning styles, a decision was made to revise the software module in the penultimate year of an honours degree.

PBL is a relatively recent advancement in learning as it was popularized by Barrows and Tamblyn (1980) at McMaster Medical School in Canada. Problem Based Learning (PBL) is a pedagogical approach that emphasises a student centred learning experience rather than the traditional teacher driven educational experience. The PBL approach is suitable for the learners on the module discussed in this paper as it moves away from the previous traditional “chalk and talk”, where information is presented to students in lectures and then examinations take place on this information at the module end. PBL presents the learners with a problem scenario and supports the learning as the students move to a problem solution. Consistent with the ‘constructivist’ model the problem activities provide the learner with opportunities to construct meaning (Biggs, 2003). While aware of the similarities between a problem based learning approach and a project based approach the author believes a problem based learning approach best describes this module, mainly due to the nature of the more open ended problem and the student driven nature of the support lectures. A PBL approach achieves not only the technological skills required of an engineer, but also the broader skills, such as a capacity for lifelong learning (Boud, 1997). PBL is used to develop independence in inquiry (Macdonald and Savin-Baden, 2004). Some studies have shown that oral and written communication, ability to work with non-engineers and skills to include social consequences in technical solutions are all improved by PBL over traditional methods (Fink, 1999). These abilities cover all the educational outcomes required for professional engineers. A programme must now show the Engineers Ireland accreditation body that their graduates have achieved these skills.

As a consequence of the learning benefits and features of PBL, it was adopted as a suitable approach for the software module in the penultimate year of an honours degree. PBL is not new to engineering, but this paper shows that the new professional requirements of education programmes may motivate a greater move towards it.

Prior to the revision of this module, software modules had only been presented in the traditional way. The students had no previous PBL exposure and had previously only done traditional year long individual projects in electronics. There were a large range of issues that needed to be addressed in the re-design of this module (Boud, 1997; Albanese & Mitchell 1993; Fink, 1999; Savin-Baden & Major 2004). For this revised module the essential components of a PBL approach were incorporated with re-structuring so that the whole module was built around one problem.

This module was previously delivered in the traditional format. There was a set of self contained summative “labs”, addressing syllabus topics, with a continuous assessment mark of 30%, and an end of semester exam worth 70%. Now the module has been revised so that it is completely driven by a defined problem. There are only 4 “labs”, down from 10 and these are only to support the learning of concepts which should be part of the problem solution. These are now formative teaching labs, with marks only awarded for completion. The module still only allocates a continuous assessment (CA) mark of 30%, with 70% still allocated for the exam, as the module is in transitional phase before the next programme review. The practitioner feels the assessment marks should be modified at that stage, to significantly increase the CA percentage. Although there is still a heavily weighted exam, the questions are very different to the previous exam as it examines the issues that will have arisen in the project, as the problem is driving the module and the level of learning. The problem CA marks are allocated as 50% individual contribution, 25% group report and 25% for the whole group’s problem solution.

The Problems

The problems were presented as a simulation of professional scenario. Each problem was described by an open ended functional specification. The problem was kept appropriately sized, as the workload in engineering programmes is relatively large, and it was important that a problem solution could be obtained in the module’s allocated time. The students did do some work outside timetabled time, but this was mainly in the reporting phase. The problems were designed so that a simple solution could be achieved by incorporating the main syllabus topics, with an improved solution expanding on the use of these topics. In this way specific problems were designed to cover critical learning outcomes. The students were informed they would need to defend their solutions when assessed. Each group was allocated a unique problem.

Group size

In the design phase it was decided that the groups should be structured as per best PBL practice, with small groups. Some PBL practitioners structure the groups with different numbers of students, but generally 4-6 is the range proposed. Three is generally found to be too few (Boud, 2004). In this project the teams were ideally to consist of 4 students, but with some flexibility as numbers dictated, as the student numbers are not usually an even multiple of four. The allocation of members to groups is discussed later in the paper.

Learning support

Stimulating the students to engage in activities that will achieve the outcomes is the primary role of the teacher (Shuell, 1986). The problem topics are challenging, with the difficulty at the level expected of an honours degree. The problem laboratory sessions were supported by the module leader. Lectures were also delivered as these classes were vital for the learners to efficiently gain exposure to topics needed for completion of the problem, but discussions and topic order were driven by the established needs of the students. Supplementary practical (laboratory) sessions were held on topics which should be incorporated in a complete solution. There was also support on effective communication, with guidance provided to resolve disagreements.

The assessment

Reluctance on the part of some practitioners to adopt PBL is often based on concerns over effective assessment, with assessment being a much debated component of all courses (Savin-Baden & Major, 2004). Also conscious that assessment drives the learning experience (Biggs, 2003) it was necessary to align the assessment method with the desired outcomes, in particular to include non-discipline specific team and communication skills.

Following consideration of the large range of options used for assessment in PBL (Macdonald and Savin-Baden, 2004) the decision was made to award marks for the problem as previously outlined . The 50% for individual contribution was an assessment of their effort and effectiveness for the team, but also their defence of their design and implementation. Although a full PBL approach would not use an exam at the end, this module used a written exam, which was designed to specifically measure the cognitive level achieved by the learner. The module was designed in this way as the students had no previous exposure to PBL, but as the programme evolves with programme revisions and PBL is introduced in earlier years, the written exam will be removed from this module.

Implementation Issues

The guidelines given to the students gave them a functional specification of the problem. They also got direction on the report and assessment method.

The learners had no prior team or PBL experience, resulting in an initial discomfort with the experience. This observation along with a loss of morale is a common experience (Boud, 2004). In their first semester of the year the teams needed specific direction as to where to start, but once the students got some general suggestions they rose to the challenges. Within a few sessions the students became self-directing. “Reflecting while doing”, the learners identified gaps they had in their knowledge of problem related topics.

They took the appropriate steps to gain the knowledge and complete all the necessary problem tasks. They were running with their ideas, and this generated many questions seeking further information on practical issues related to the subject topics.

The students were provided with material to stimulate discussion on techniques that could be incorporated into their problem solution. This material was presented in a class, with a general discussion on how it could be used in the various problem solutions. Discussions took place on the concept, its advantages, difficulty of implementation and any other issues of interest to the students. In order to sensitise the learners to the ethical nature of any arising decisions they were encouraged to consider the concepts of universal design, data protection, safety critical design or any ethical implications.

The group formations

In the design phase of this module revision it was decided that the groups should be small, ideally of 4 people. As the students had no prior experience of a team situation they initially expressed concerns over the fairness of the assessment in a group scenario. This was particularly a view of students who had excelled in the traditional individual work mode. When the students were asked for written feedback at the end of the semester they expressed no concerns about assessment fairness. There was some feedback on the allocation of team members. Initially the team members were allocated randomly. The students gave feedback stating that they would prefer groups to be formed so that all team members were available for non-timetabled work at the same time. This was a practical issue based on different domestic or travel circumstances. While conscious that the purpose is to simulate reality as much as practically possible, a decision was made to revise the method of group allocation for the subsequent semesters following this feedback. The groups are currently self selecting, but with the condition (imposed if necessary) that there must be a spread of levels based on historical performance, and everyone must be satisfied. Otherwise groups are allocated randomly. This is to prevent any elite groups or exclusion. It has not been necessary to revise the self-selecting groups.

Group Activities

The student activity was directed towards the latest group determined tasks. It was important to re-enforce the idea of effective communication (with listening) within teams. Once the first few sessions had passed the teams were conscious of communication, with more effective resolution of any issues.

Testing and Evaluation

Through the process of working on the problem the learners achieved discipline specific skills which are the usual objectives of traditional methods, such as an ability to derive and apply solutions. They also showed an ability to identify and solve engineering problems, as well as the ability to design a system to meet specified needs.
When a comparison was made between the last year without a PBL approach and the current year with a PBL approach, it was found that the marks increased, but it is accepted that this is not a measure of the effectiveness of the PBL approach, as the assessments were different between the PBL and non PBL approaches, as outlined earlier in the paper.

It is believed that a more effective measure of the PBL approach is to measure the level achieved in the cognitive domain as categorised by Bloom's Taxonomy (Bloom, 1956). The highest measured level is a good indicator of cognitive status as the achievement of a level in Bloom's Taxonomy indicates that all previous levels have been achieved. In order to measure the effectiveness of the adopted PBL approach the student's assessments were benchmarked against the illustrative verbs for Bloom's Taxonomy's level of learning. This showed that the PBL approach not only improved the results but it improved the cognitive level examined and demonstrated by the learners.

	Bloom Taxnonomy highest level	Verbs indicative of this level (used in assessment questions)
Without PBL, written exam	Application (level 3 of 6)	Write code. Implement.

With PBL, written exam	Synthesis (level 5 of 6)	Design. Compare and contrast (could argue is this analysis or evaluation level!)
With PBL, Oral examination.	Evaluation (level 6 of 6)	Justify. Defend choices in design and implementation

Figure 1 : learner achieved Bloom's Taxonomy cognitive level

Figure 1 shows that using the traditional approach the examination tested up to the application level of Bloom's cognitive domain. In the PBL approach the learners were assessed up to the highest 'evaluation' level and were assessed throughout the time they worked on the problem and so could not rely on rote learning as they developed and defended their designed solution.

In the revised module, with a PBL type approach, the written report required the learners to explain their choices, design and implementation, and in the oral examination, the learners were required to justify and defend their choices. In future, instructions to students will specifically state that a justification of techniques is required for the report, as this will increase the emphasis on this learning outcome and will be assessed in both the written report and orally. The individual contribution marks were allocated based on the observations and discussions throughout the year and on the oral examination. This required more than rote learning as they knew the practitioner was assessing their contribution to the team effort and that they would need to defend their solution in an oral examination. The marks were based on what cognitive level they had achieved and what they brought to the team effort.

The traditional module delivery only examined discipline specific technical skills. A vital motivation for the introduction of PBL was the required non-discipline specific transferable skills not addressed under the traditional mode. Using the PBL type approach the learners showed they not only increased the level of learning achieved in the technical skills, they also obtained a range of the transferable skills required of professional graduates. The module discussed in this paper provided the learners with a team activity and a successful team outcome was achieved, with each team generating a problem solution. The students showed how they were able to direct their own learning as they discovered gaps in their knowledge to complete the problem. Once they uncovered the gaps they took the necessary steps to address the deficiencies, showing a capacity to undertake lifelong learning. It was also necessary to present their solution and communicate its workings, followed by questions to each individual member of the team. Thus through the PBL experience students obtained the communication skills required of professional engineers.

Conclusions & Further Work

This paper has described the movement of a software module in an engineering programme to a PBL type approach that has enhanced the learning experience and has been a success. The module has achieved learning outcomes in discipline specific skills, but also additional transferable skills required for professional engineering membership. The learners gained skills for lifelong learning; being able to self-direct, determine and address gaps in their knowledge. They learnt how to work effectively in teams, communicate both orally and in a written format. This showed that PBL is a suitable approach to produce professional engineers.

It was a challenge to the practitioner, but a positive and satisfying experience. The students also appeared enthused, with increased engagement, and with lots of questions seeking further information on practical issues related to the subject topics.

While it was a success, it is believed that further enhancements could improve the effectiveness of the learning and teaching. At the next opportunity the assessment will be revised further, as outlined in the assessment section of the design. The guidelines for the assignment report will also put a stronger emphasis on justification of solution, as discussed in the previous section. Currently, the examination is closed book, but the assesment will be revised this year to an open book exam, further emphasising the higher level cognitive skills required of the learners.

There is ongoing enthusiasm within the school to deliver a progressive learning environment. Due to overall programme revisions future students will have prior exposure to the roles within teams and the dynamics of a team. This should lead to progressive improvement in team effectiveness skills as well as lifelong learning skills. The effects of the prior experience, which will be the case from now on, will be examined in the coming year.

It has been stated that exposure to a PBL experience increases a student's ability to work with non-engineers (Fink, 1999) and creates graduates who are more conscious of the social consequences of their technical solution (Fink,1999). These are both outcomes demanded of professional engineers. These outcomes have not been tested so far for the students taking this module, but it would be a beneficial evaluation to further confirm the fact that the use of PBL is more effective at producing professional engineers.

The Felder-Silvermann model learning style preferences were examined in first year student, but it would be beneficial to establish if the group profile has changed over the years by re-testing the student's learning preferences just before they start this module.

In Bloom's later work he categorised the affective domain within Bloom's taxonomy (Bloom, 1964). As an objective of the programme is to produce professional engineers, with the requirement to not just have the knowledge, but to work in teams, an evaluation of their affective domain level would be beneficial. It is believed that the PBL type approach has improved the level in this domain, and it is planned to develop a quantative measure for future evaluation of module and programme modifications.

While there are further enhancements and testing that could be added to the PBL approach adopted in the software module in the penultimate year of an honours degree, this paper has shown that effective integration of PBL should be a suitable approach to produce professional engineers.

References

Albanese, M.A. & Mitchell, S. (1993). Problem-based learning: A review of literature on its outcomes and implementation issues. *Academic Medicine*, 68, 52-81.

Barrows, H. S. and Tamblyn, R. M. (1980) *Problem-based Learning, An approach to Medical* Education, Springer, New York.

Biggs, J.B. (2003). *Teaching for quality learning at university 2nd ed.* Open University Press/Society for Research into Higher Education, Buckingham.

Bloom, B., & Krathwohl, D. (1956) "Taxonomy of Educational Objectives: Cognitive Domain". David McKay Co. inc, New York.

Bloom B., Mesia B. , & Krathwohl D. (1964) /Taxonomy of Educational Objectives : Affective// Domain/. David McKay Co. inc, New York.

Boud, D., & Feletti, G. (1997) *The challenge of problem-based learning (2nd ed.)*. Kogan Page, London.

Cranley F., O'Sullivan C. (2005). Analysis of learning styles in a first year engineering course. *Proc. Intl. Manufacturing Conference*, 22, 327-337.

Engineers Ireland (2007). "Accreditation Criteria for Eng. Ed. Programmes".

Felder R.M. , Silvermann L.K. (1988). *Learning Styles and Teaching Styles in Engineering Education* Engr. Education*, 78 (7).*

Felder R.M. Spurlin J.E. (2005). "Applications, Reliability, and Validity of the Index of Learning Styles," *Intl. Journal of Engineering Education*, 21(1), 103-112.

Fink, F. K. (1999). Integration of Engineering Practice into the Curriculum – 25 years of experience with Problem Based Learning. *IEEE frontiers in education conf.*

Macdonald and Savin-Baden. (2004). A Briefing on Assessment in Problem-based Learning. *LTSN,* Assessment Series No 13.

Savin-Baden, M. and Major, C. (2004) *Foundations of Problem-based Learning*. Open University Press/SRHE, Maidenhead.

Shuell, T.J. (1986). Cognitive conceptions of learning. *Review of Educational Research*, 56, 411-436.