Problem-Based Learning in the Engineering Curriculum – Is it suitable for first year undergraduates?
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Abstract

Problem-based learning is an educational approach that originated within medicine, and has been used in other disciplines such as engineering and economics. This article explores the question of whether it could be applied within the undergraduate engineering curriculum at my institution. This is achieved by considering my own experience as a teacher within engineering and through discussion with peers and colleagues, as well as considering the advantages and disadvantages of both the current curriculum and Problem-Based Learning. The article concludes that there is potential for such an approach to be included within an engineering curriculum, but there are certain obstacles, particularly in the early stages of an engineering degree program, and therefore it may be more appropriate in the latter years of such a course of study.

Keywords: problem-based learning; engineering; curriculum design.

Introduction

I am a researcher in the College of Engineering, Mathematics and Physical Sciences (CEMPS) at the University of Exeter, and I teach and demonstrate in tutorials and laboratory classes on an undergraduate engineering module. Through participation in the Postgraduate Certificate of Academic Practice (PCAP) and reflection on my teaching, I have come across the concept of Problem-Based Learning (PBL). PBL is an educational approach that uses problems as the stimulus and focus for the learning activity. It was introduced to the medical curriculum in 1969 at McMaster University in Canada, and has been extended to other fields of study, such as my own specialism, engineering (Cawley 1991). In the literature, there are many definitions of PBL, although a fairly succinct formulation which serves as a good starting point is offered by Wilson (2004):

‘At its most fundamental level, PBL is characterised by the use of real world problems as a context for students to learn critical thinking skills and problem solving skills and to acquire knowledge of the essential concepts of the course.’

The overarching question I would like to consider is whether Problem Based Learning (PBL) would be appropriate in a first year engineering undergraduate curriculum, and if so, how it could be implemented.

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I would like to tackle this question in several steps. I will begin by describing in more detail the teaching in which I am involved. I will also describe the feedback from students in order to consider the weaknesses and strengths of the current teaching approach. Second, I would like to consider the theoretical background to PBL in more depth. Third, I will discuss the advantages and disadvantages of PBL, by making reference to education literature. Fourth, I will consider the implications for the College of introducing PBL. Finally, I will make some conclusions on the suitability of PBL in the undergraduate engineering curriculum.

Current teaching experience

I teach on an engineering mechanics module for first year undergraduates. Lectures, given by other members of staff, introduce the main concepts and provide a broad background. The lectures usually provide limited opportunities for student interaction. These lectures are then followed by a series of tutorials or demonstration classes. The cohort of students is broken down into four groups of around 30 students, and I take the classes for two of the four groups. In addition to these tutorials, there are also laboratory classes which can be used to demonstrate engineering principles in a practical setting.

In a two hour tutorial session, the students are presented with several questions or problems that relate to engineering systems, and attempt to solve these problems by applying the theoretical principles presented in the earlier lectures. My current practice is typically to provide the students with some time to reflect on the problem, and to begin working on the problem. After some time has elapsed, I attempt to engage the students by asking questions, and then tackle the questions together in front of the class. I encourage students to ask questions, although I sometimes find it challenging to develop this sort of interaction.

I investigated the views of the students using the University’s Module and Course Evaluation (MACE) data. The data is merged for both parts of the module, but the majority of respondents agreed that the course was interesting and stimulating (79%), that the module is well structured (73%) and that the staff were enthusiastic (88%). However, although still a majority, only 60% thought the module was at the right level of difficulty, and 63% agreed that the material was explained clearly. This suggests that some students were finding the material difficult, despite the enthusiasm of the teaching staff. This was reflected in some of the written comments. Although the module feedback was generally positive, there is clearly some scope for improvement. This provides the motivation for considering whether PBL could be introduced into the first year engineering curriculum. To consider the suitability of PBL, I need to have a clear understanding of what it involves, and the next section will review the literature on PBL.

What is Problem-Based Learning?

PBL has been described as ‘reflecting the way people learn in real life’ (Biggs and Tang 2007). PBL was originally introduced into medical curricula, and one of the key researchers was Howard Barrows, who wrote that PBL ‘is the learning that results from the process of working toward the
understanding or resolution of a problem. The problem is encountered first in the learning process’ (Barrows and Tamblyn 1980, 1). Barrows (1996) defines six characteristics of PBL:

- Learning is student centred.
- Learning occurs in small student groups.
- Teachers are facilitators or guides.
- Problems form the original focus and stimulus for learning.
- Problems are a vehicle for the development of clinical problem solving skills. These problems should be open and ill-defined.
- New information is acquired through self-directed learning.

PBL is considered as coming from a Constructionist perspective. Constructivism is a collection of theories that claim that people ‘construct’ their own meaning by building on their previous knowledge and experience. Constructivism is therefore a dynamic process where small localised changes in these ‘constructs’ may lead to changes in overall understanding (Carlile and Jordan 2005). Social Constructivism is a more specific set of ideas, largely developed from the ideas of Vygotsky (1978), that emphasises the social nature of learning. The social constructionist philosophy that underpins PBL can be linked with the idea of ‘Communities of Practice’, as described by Etienne Wenger (1998).

‘Communities of practice are formed by people who engage in a process of collective learning in a shared domain of human endeavor: a tribe learning to survive, a band of artists seeking new forms of expression, a group of engineers working on similar problems, a clique of pupils defining their identity in the school, a network of surgeons exploring novel techniques, a gathering of first-time managers helping each other cope.’

According to Carlile and Jordan (2005), these ideas imply the need to promote discussion and small study groups, the need to develop relations between learners, and the benefits of collaboration and team work. However, in moving from theory to practice, a jump has to be made. Kirschner et al. (2006) write that

‘Constructionism is based ... on an observation, that although descriptively accurate, does not lead to a prescriptive instructional design theory or to effective pedagogical techniques.’

Perrenet et al. (2000) highlighted the problem that PBL may not lead to learners ‘constructing the right knowledge’. The effects of PBL on knowledge acquisition will be discussed later.

There are clearly some similarities between PBL and my tutorials. Firstly, Boud and Feletti (1991, 13) state that ‘the principal idea behind problem-based learning is [...] that the starting point for learning should be a problem, a query or a puzzle that the learner wishes to solve’. My tutorials do use ‘problems’ in the learning process. Second, in tutorials, I strive to be a facilitator, although it can be difficult to avoid ‘chalk and talk’. Third, tutorials are more student-centred than the traditional lectures.
However, there are several reasons why the classes I teach are not PBL as originally envisaged. The problems are not presented before the material that is to be learned. The problems in the tutorials are intended to reinforce the material covered in the lectures. In addition, the problems presented in tutorials are not sufficiently ill-defined or open-ended. There is typically one correct answer.

PBL, as properly defined, can be contrasted with the type of problem-solving that takes place in my current tutorials, as in this quote from Barrett (2005):

‘One of the most important points about problems in problem–based learning is that it is not a question that first the students receive inputs of knowledge e.g. lectures, practicals, handouts etc. and then ‘apply’ this knowledge to a problem they are presented with later in the learning process. This type of a situation is not problem–based-learning, it is problem solving’.

This reiterates the key point that in PBL, the problem is presented before the learning. I would like now to tackle the question of whether PBL (or more elements thereof) could be introduced to the undergraduate education. I begin by considering the supposed benefits and disadvantages of PBL at greater length.

Advantages and disadvantages of PBL

Within education literature, there are many claimed advantages to PBL, for students, teachers and the university. Some of these advantages have been summarised by Pawson et al. (2006), and Dolmans and Schmidt (1996). The first common argument is that PBL promotes deeper learning and therefore a greater understanding of the subject with more knowledge retention. The concepts of deep and surface learning were introduced by Marton and Säljö (1976). Students were asked to read a text, and the authors were able to distinguish students who ‘skirted along the surface of the text’, rather than those who looked for the ‘big picture’. Importantly, the terms deep and surface relate to the approaches adopted, not the students themselves.

However, there are some potential problems with this argument. Firstly, a deep learning approach may not always be appropriate. There are some tasks where a mixture of approaches might be more suitable, such as the learning of key equations. Such an approach is termed a ‘strategic approach’ (Newble and Entwistle 1986). A second criticism hinges on the empirical evidence for the claim that PBL can lead to a change in learning styles. McParland et al. (2004) found an improvement in the examination results of a cohort of psychiatry students who had attended a PBL course. However, they did not find evidence for the claim that this could be attributed to any change in learning style. The course was short, and PBL might require more time to have any significant effect on the students. Thirdly, the evidence for an improvement in the knowledge base of PBL graduates is limited. It is even claimed by some that PBL may lead to a reduction in basic science knowledge. For example, Albanese and Mitchell (1993) found that the knowledge base of PBL students was consistently lower than that of non-PBL students. However, there is some conflicting evidence in the literature. In a review of the medical educational literature on PBL between 1992 and 1998, Colliver
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(2000) found no convincing evidence that PBL had led to an improvement in the knowledge base of graduates. In a more recent study, biological science students who had undertaken a hybrid PBL-lecture based course were contrasted with those who had taken a traditional lecture-based course, and found no significant differences in knowledge base (Carrio et al. 2011). In an interesting meta-review from forty-three studies across tertiary education, Dochy et al. (2003) found that PBL students tended to learn less but retain it for longer.

Two interesting papers, the first by Kirschner et al. (2006), and a reply by Hmelo-Silver et al. (2007), set out arguments for why PBL may or may not work in terms of knowledge acquisition. Kirschner et al. (2006) argue that there is significant evidence that ‘guided instruction’ methods are superior to ‘unguided instruction’ or ‘minimal guidance’ methods such as PBL, and that these latter approaches are inefficient and ineffective. They quote a report for the US National Academy of Sciences that provides evidence for the negative consequences of unguided science instruction at all age levels and across a variety of science and mathematical content (McCray et al. 2003). In response, Hmelo-Silver et al. (2007) argue that PBL differs from minimally guided ‘discovery learning’, and that PBL provides ‘considerable guidance to students’ through ‘scaffolding’. They argue that scaffolding presents

‘learners with opportunities to engage in complex tasks that would otherwise be beyond their current abilities. Scaffolding makes the learning more tractable for students by changing complex and difficult tasks in ways that make these tasks accessible, manageable, and within [the] student’s zone of proximal development.’

A second claim in favour of PBL is that it promotes the development of more general skills, such as problem solving and self-directed learning, as well as communication and group working skills. These claims make intuitive sense, and there does seem to be good empirical evidence for this claim. In a study on the experience of PBL classes in chemical engineering over a period of 13 years, it was reported that the students were more comfortable with self-directed learning and problem solving, and employers’ perceptions of the graduates were positive, with one quoted as praising the ability of the graduates to ‘think for themselves and solve problems upon graduation’ (Woods 1996). In a review paper, Blumberg (2000) found evidence that PBL promoted self-directed learning skills, using self-reported data from students as well as evidence from faculty staff. However, there is some contrary evidence, and while Loyens et al. (2008) conclude that most studies were in agreement with the claim, its effect is dependent on how it is implemented, including factors such as class size.

A further commonly made claim in favour of PBL is that it is a student-centred approach, which students and teachers find more enjoyable. In a review of PBL in medical curricula, Albanese and Mitchell (1993) found significant evidence of higher satisfaction among students who took PBL classes. Indeed, this might be the strongest point in favour of PBL. In a fairly critical paper on PBL, Norman and Schmidt (2000) wrote that

‘PBL does provide a more challenging, motivating and enjoyable approach to education. That may be a sufficient raison d’être, providing the cost of implementation is not too great.’
The additional staff resources required for a PBL curriculum, given the smaller class sizes, is a commonly quoted disadvantage, and this will be important when I discuss the possible implementation of PBL within the College, in the following section.

What are the implications for introducing PBL in the engineering curriculum in CEMPS?

The possible introduction of PBL into undergraduate engineering education provides a number of positive opportunities for the College (CEMPS) and its students. The first major opportunity is that PBL aligns with many of the stated aims of the University. For example, the University’s Education Strategy for 2010 – 2015 has eight core principles, one of which is ‘to promote and enable active and collaborative ways of learning’, which PBL exemplifies, as well as ‘plac[ing] research at the heart of the learning experience’ (University of Exeter 2012). Some of its implications have been addressed in a discussion paper (Fung 2011). Here, it is argued that the

‘core principle ... [is that] ... a rich community of cutting edge, international researchers is best placed to enable students to learn in research-like ways ... To learn in the way that a researcher does is to learn actively, critically and creatively.’

Jenkins et al. (2007), in a report for the Higher Education Academy, argue that the teaching-research nexus (described as the connection between research and student learning) is central to higher education. They argue that focusing on the teaching-research nexus can ‘aid students’ learning, their pride in their discipline and department, staff morale, and the overall effectiveness of the department and the institution’. However, they make the key point that these connections do not happen naturally but rather that they have to be created. They give a case study of a PBL class within an Environmental Management degree at the University of Queensland as one way through which this connection could be strengthened.

The strengths of PBL can also be linked with the UK’s Quality Assurance Agency for Higher Education (QAA) Benchmarking Statement for Engineering, which describes the expected characteristics of an undergraduate degree program and its graduates. For example, engineering graduates should have greater capacities for ‘dealing with open-ended and unfamiliar problems’ (QAA 2010). According to one senior academic, there has been a shift away from what is being taught towards what is being learned and the wider skills that graduate engineers are expected to possess. This is reflected in the professional standards of a Chartered Engineer in the UK. For example, a Member of the Institution of Civil Engineers is supposed to demonstrate certain attributes, such as the ‘ability to conduct appropriate research, and undertake design and development of engineering solutions’. Self-directed learning skills are reflected in these attributes, by the need to demonstrate ‘commitment to current and future Continuing Professional Development’. The course lecturer pointed out that there was an opportunity to improve the way students understand the material, and that new techniques such as PBL should be considered. However, he questioned whether PBL was the most efficient use of resources.
I discussed PBL with another senior academic, who made several points. If PBL is more enjoyable than other, more traditional, teaching methods, then it has the potential to increase student retention, as well as improving the results of the National Student Survey upon which the University is judged. They told me of a second year course in Telecommunications, where elements of PBL, in the form of project work, have replaced more traditional lecture courses. Here, students were motivated by the practical and industrial relevance of the module.

The excitement from tackling real problems was something that was highlighted to me by another lecturer who runs industrial case study classes. They found that introducing students to work that was industrially relevant increased their interest in the subject. She was also aware, however, that there was a risk involved. She found that some students were anxious when they were out of their ‘comfort zone’, but she noticed an improvement in the students’ abilities and in their confidence as the course progressed.

As well as the opportunities, then, there are clearly several obstacles to introducing PBL into the curriculum. Firstly, the staff resources required could be a problem. PBL class sizes are typically of the order of 10 to 20 students. Currently, 130 students are enrolled on the course on which I teach, and tutorial classes are held in groups of around 30 students. Smaller groups would mean more staff were required, or more time. In a research-intensive environment such as the University of Exeter, resources taken away from research could have serious implications for the Research Excellence Framework, the successor to the Research Assessment Exercise.

A second barrier is the need for additional staff training. According to a lecturer in the Peninsula Medical School, who is a PBL facilitator, different skills are required from traditional ‘chalk and talk’ lecturing. The facilitator must be able to encourage student discussion through challenging open-ended questions, as well as listening to the discussion and avoiding the temptation to intervene.

A third barrier is the nature of engineering and how it differs from medical knowledge. It has been argued that medical knowledge has a more encyclopaedic structure, and so the order in which things are learnt may be less important, and gaps can be filled in later (Perrenet et al. 2000). This can be contrasted with engineering, where the structure of knowledge is more hierarchical, and where certain topics must be learned in a particular order (Mills et al. 2003). This is a point that was made to me by a senior academic within the College. They argued that although PBL has many potential benefits, students could miss out on the fundamental knowledge required in later years, especially the less able or committed students.

One opinion presented to me was that as students are increasingly being considered as ‘consumers’, there may be an increasing expectation that all learning material should be provided. The Exeter Learning Environment (ELE) platform has been developed to aid this process. I have also observed students who seem to either lack the confidence or the skills to work on problems for themselves. The risk is that students simply are unaccustomed to such teaching methods and may struggle, although PBL does provide an opportunity to remedy these skill shortages. This conflict could be resolved through the progressive introduction of PBL elements into the curricula.
A further obstacle to PBL is that it may present challenges for students from different cultural groups. Favouring teaching styles that are challenging for certain groups might lead to dissatisfaction among students. In one study, international (Chinese) students who were enrolled on tourism-related courses in the UK were surveyed to elicit their views on PBL, contrasting it with traditional Chinese styles of teaching (Huang 2005). The author argues that it is typically thought that Chinese students prefer a passive style of teaching, and that problem solving teaching methods would ‘not fit the Confucian-derived preferences for rote learning’. The vast majority of students in the survey enjoyed the classes. However, there were some noticeable negative perceptions. 80% of the students admitted they were uncertain about the accuracy of the knowledge gained in class, and over 70% of the students were unsure as to whether they had understood the material. One student was quoted as saying ‘The Chinese style of learning is typically teacher-centred, stressing recall of facts ... It uses strict exams to develop academic knowledge. It is a typical style in which concepts come first then skills. However, although it is a boring approach to learning about new facts, you know exactly what you should learn.’

Another barrier to the implementation of PBL might be a form of conservatism or inertia within the College. Boud and Feletti (1991) have written of the problems that arise when PBL has been proposed without sufficient commitment from staff at all levels, and so this might present a significant challenge.

This links with the final risk and opportunity for PBL, which is ensuring that the course is well designed. Good course design can be helped by the idea of Constructive Alignment, developed by John Biggs. According to Biggs and Tang (2007), Constructive Alignment ‘reflects the fact that the learning activity in the intended outcomes ... need to be activated in the teaching if the outcome is to be achieved, and in the assessment tasks to verify that the outcome can been achieved.’

One of the stated Intended Learning Objectives (ILOs) of the course is that students should be able to ‘apply principles of statics and dynamics for both solids and fluids to the analysis of simple mechanical systems’. Importantly, this ILO contains a verb, ‘apply’, and describes what the students should be able to do. As such, a well designed PBL curriculum provides an opportunity to align this ILO with the teaching and learning methods.

There are many examples of PBL courses being used in an engineering setting. For example, Cawley (1991) writes of a final year module in a Mechanical Engineering programme. The author, who designed the course (and may be prone to bias), concluded that it was more enjoyable for both the students and the lecturer. Mills et al. (2003) cited examples of PBL in Civil Engineering at the University of Monash in Australia, Hydraulic Engineering at Pennsylvania State University, and Water and Wastewater engineering at Griffith University, Queensland, Australia.

According to a colleague who uses PBL in a medical curriculum, the design of the problem is of great importance, and will be the subject of her PCAP assignment. In their words, a trigger must be
complex and open-ended. The problem should be able to relate to the prior knowledge of the students. This may be more difficult for first year students where their prior knowledge can vary greatly. The problem must also be intrinsically interesting.

It is clear from the earlier quoted discussion between Kirschner et al. (2006) and Hmelo-Silver et al. (2007) that for PBL to be successful, sufficient ‘scaffolding’ (based on the ideas of Jerome Bruner) or structuring must be supplied, and this relies on good facilitators. Hmelo-Silver et al. (2007) quote some examples of good scaffolding, such as where the facilitator frequently pushed students to explain their thinking or to identify the limits of their knowledge. Teachers can also provide students with models to structure their thinking. For example, white boards can be used to encourage the students to organise the facts, the hypotheses, the learning actions, and the action plans. Teachers can also embed their expert guidance through hints and direct explanations when students are struggling. The role of facilitator is not an easy one, and considerable effort would have to be expended before the possible introduction of PBL.

Conclusions

PBL is clearly an interesting and promising technique for teaching and learning. There is good evidence that PBL promotes a number of skills such as self-directed learning, communication and group working skills. In addition, it is a stimulating and enjoyable way to learn. The evidence on its effect on the knowledge acquisition of students is less clear cut. To be successful, teachers must provide good scaffolding, and this requires significant skills. But PBL provides an opportunity to meet the University’s wider goals and the expectations of professional engineering institutions.

However, introducing a PBL curriculum presents several problems. Firstly, the hierarchical nature of engineering knowledge suggests that learning the fundamentals is crucial, and thus PBL could result in less able students missing the basics. Secondly, the resource costs needed to implement PBL classes are significant, not only in terms of operating the classes, but also in the redesign of modules. This problem is more pressing in the early years of a degree when the class sizes are much larger. A third problem is that the early year undergraduates may not possess the confidence required to work in a self-directed manner. However, these three problems can be overcome to an extent by the implementation of PBL in the later stages of an undergraduate engineering degree, particularly in more open-ended design classes. The problems of course design, staff commitment and resistance to change exist if PBL were introduced at any stage in the degree program, and would need to be challenged with information, education and encouragement.

On balance, I think PBL could be considered more widely in the curriculum in CEMPS, although I would not recommend it in the first year module. I would suggest it could be introduced at later stages of the degree program, while maintaining the traditional lecture-style teaching methods that are used predominantly in the early years.
References


