

Teaching Physics to Engineering Students Using Problem-Based Learning*

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This paper describes how problem-based learning can be used to teach physics to first-year engineering students. The problem-based learning pedagogical approach promotes the development of key skills such as problem-solving and group skills. A model of problem-based learning is then suggested for use with first-year students and the implications of its use are detailed. The evaluation of this PBL course is outlined. This paper should be of particular interest to anyone who is not in a position to convert a complete course from traditional teaching methodologies to problem-based learning but would like to introduce it into one part of a course.

INTRODUCTION

IT IS IMPORTANT to have a clear understanding of the distinction between learning via problem-solving learning and problem-based learning (PBL). In teaching engineering and physics, the use of problem-solving learning is well established. In this method, the students are first presented with the material, usually in the form of a lecture, and are then given problems to solve. These problems are narrow in focus, test a restricted set of learning outcomes, and usually do not assess other key skills. The students do not get the opportunity to evaluate their knowledge or understanding, to explore different approaches, nor to link their learning with their own needs as learners. They have limited control over the pace or style of learning and this method tends to promote surface learning. Surface learners concentrate on memorisation, whereas deep learners use their own terminology to attach meaning to new knowledge [1].

Problem-based learning (PBL) is a teaching methodology based on a different philosophical approach to teaching and learning. PBL is characterised by the organisation of curricula around real-life problem scenarios. The students are presented with these problems and work in groups towards a solution. The students determine their learning issues and develop their unique approach to solving the problem. The members of the group learn to structure their efforts and delegate tasks. Peer teaching and organisational skills are critical components of the process. Students learn to analyse their own and their fellow group members' learning processes and, unlike problem-solving learning, must engage with the complexity and ambiguities of real-life problems. If problem-based learning is used

throughout a complete course, it also allows the students to integrate their knowledge and learning across subjects and disciplines. It is a flexible approach to teaching and has been implemented in a variety of ways across a broad range of disciplines [2]. It is ideally suited for the development of key skills, such as the ability to work in a group, problem-solving, critical powers, improving personal learning, self-directed learning, and communication.

Although problem-based learning is grounded in the developmental or experiential learning tradition, where learning is viewed as an active process [3], it does share many of the requirements and characteristics of the other learning theories. Problem-based learning has many similarities with active learning based on Dewey's [4] suggestion that learning is an activity or a process of finding out in which learning only occurs by doing. The advantage of problem-based learning over other teaching methodologies is its flexible approach to students' learning styles. While conventional lectures assume that all students can learn by listening, problem-based learning allows students to learn in a way that suits them and it also encourages them to evaluate their way of learning.

Problem-based learning models

Engel [5] suggests that the strict problem-based learning model, as devised by Barrows and Tamblyn [6], be followed if one is not to diminish the ability to promote particular learning principles. However, Barrows [7] and Savin-Baden [8] suggest that problem-based learning has many guises and must be adapted to suit disciplines and knowledge base. There has been reluctance to introduce problem-based learning into first-year physics courses, due to the pedagogical view that the students require a sound body of knowledge and mathematical skills before they are equipped to engage with this process. When problem-based

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learning has been introduced, it has tended to be in the final year of the course [9]. It has been found in research that first-year students tend to rely more on lecture notes than students in later years [10] and that they tend to be assessment driven [11]. However, the authors have shown that problem-based learning can be successfully introduced into the first year if it is facilitated correctly and the tutors are aware that the students are only in the early stages of developing as self-directed learners.

FIRST-YEAR PHYSICS COURSE

This section details a model of problem-based learning used in two first-year physics courses in the Dublin Institute of Technology. The first course is a mathematical physics course and the second is a complete first-year physics course. Much of what is described here stems from student evaluation and feedback obtained over the last three years. Unlike many science and engineering courses, both content and key skills are part of the learning outcomes. We shall outline the parts of our PBL process: the orientation programme, the problem development process, the group process, the assessment/feedback process, the reflection process, and the tutorial support.

Orientation program

Research by Taylor and Burgees [12] suggested that students starting a problem-based learning course for the first time are at different stages of readiness for self-directed learning, and that they would benefit from an orientation course which highlights: the lecturer's expectations of self-directed learning; the role of the facilitator; the principles and practices of learning in groups; and issues of time management. In order to address these findings, an orientation programme was developed which introduces and explains the PBL rationale and philosophy, the teaching methodology, assessment strategies and the learning resources which are available to the students. The orientation process is designed to be interactive and discursive and allows students to experience group learning for the first time as they work together to solve puzzles and trivial problems. We have found that a well-designed and well-run orientation programme is critical to the success of introducing PBL.

Problem development process

Research carried out in Maastricht University showed that the most important elements for a successful problem-based learning course are the tutor and the problems [13]. In designing our problems, we started by listing the learning outcomes and then developing appropriate problems which would allow the students to achieve those outcomes. It is crucial to design the problems in such a way that the students are forced to achieve the required learning outcomes in order

to reach a solution to the problem. The problems were developed along with an assessment strategy before the course was launched. Initially, problems were developed which covered particular sections of the physics curriculum (e.g. mechanics or optics), but the authors hope to use a more integrated approach next year, where an individual problem may cover two or more distinct areas of physics, as we believe that this is necessary in order that students perceive physics as an integrated whole rather than as a collection of independent parts.

Group process

The students work in groups to solve a problem. A typical group size is six students and, at the start of the year, each group will have a tutor observing the process and acting as facilitator. During the first few problems they learn about group work and start to develop their interpersonal skills. At first the idea of a physics problem with no single correct answer or solving strategy inhibits the students' learning. It is only after the students have had a number of group sessions that they begin to evaluate the problem in terms of prior knowledge and experience. During these brainstorming sessions, the problem scenario becomes clearer, allowing them to evaluate what knowledge and skills they will need to solve the problem. The process of explaining something to the rest of the group proves challenging even for the best of students. The students attribute this to the fact that they have never had to explain any of their knowledge to a peer. The students then find themselves facing the task of defending their knowledge if challenged by a peer. It is these situations that allow the students to gain a thorough understanding of the knowledge they already have and evaluate the gaps in this knowledge.

Initially, the students use the 'four-columns' technique [6], where they list the facts, ideas, learning issues and tasks. However, as the course develops the students develop their own strategies based on the four columns. The process can be loosely divided into the following steps:

- *Group process*
 - Presentation of the problem
 - Delegation within groups
 - Brainstorming sessions with tutor questioning
 - Tutor observation, direction and support
 - Groups determine learning needs
 - Peer-tutoring
- *Independent study*
 - Source material
 - Critical analysis
 - Self-directed learning
- *Group process*
 - Critical evaluation of acquired knowledge
 - Peer tutoring
 - Tutor interaction
 - Working towards a solution and understanding through consensus
 - Presentation of solution by report or presentation
 - Reflection on the process

Assessment/feedback process

After working on a few problems, the students become more aware of their roles and the expectations the tutors have of them as individuals and as group members. The group is continuously assessed and the students are given regular feedback. A complete but simple assessment criteria for the group process was developed and includes such things as their level of contribution, peer-teaching, questioning, and completion of group-assigned tasks. Based on these criteria, each student is given a mark for their work and these marks are supported with extensive feedback.

Self-assessment is introduced about halfway through the academic year. The students attend a workshop where the rationale and objectives of self-assessment are explained followed by a negotiation of the assessment criteria. From this point on, after every group session each student is required to evaluate his or her own contribution to the group process and award a mark based on the criteria. The students complete a form on which they write a mark out of ten and justification for that mark. To develop into self-directed and metacognitive learners, the students are required to explain where they lost marks and describe what they would do differently in the next session.

Upon completion of a problem, the group produces a report or gives a presentation, both of which have detailed assessment criteria. This continuous assessment and feedback process is designed to assist student learning and promote deep learning. To augment this process, a WebCT on-line learning resource was developed. While the WebCT site includes course information, a calendar, links to other physics sites, simulations, quizzes, tests and communication tools, it is mainly used as a vehicle for the tutors to provide feedback to the students.

Reflection process

Reflection is a key process in transforming and integrating new experiences and understanding with existing knowledge [3] and is of critical importance when students are adapting to a new teaching methodology. In order to force the students to reflect on the learning process, they are asked to reflect on the problems, the solving strategy they chose, the learning outcomes, the abilities they developed and problem-based learning. At first this can be a very didactic process whereby the information has to be coaxed from the students, but, with familiarity with the process, it becomes more discursive. Initially, it surprises the students to see that they are learning so much and developing key skills, but this is all part of the learning process and the development of their learning identities.

Tutorial support

The physics students are given regular tutorials or review lectures on some of the theory or

problem-solving tools they will have learned by solving the problem. The purpose of this is to reaffirm the knowledge the students have gained and to give them confidence in themselves and the teaching technique. It also allows them the opportunity to assess their learning and evaluate their learning needs. The students are made aware of the objectives of these presentations, so that they do not come to rely on this for their learning but only use them to reaffirm and check the level of their learning.

We have found that problem-based learning in this form is very successful with first-year students. However, implementing PBL without providing the necessary learning resources and support for the students can result in the students becoming disillusioned and failing to learn. If implemented properly the immediate results are highly motivated students who are willing to interact and reflect. This has a 'snowballing' effect as the students make the tutor aware of the problems they are having and challenges they encounter. The tutor can then either make changes to the course or help the students develop the necessary skills and abilities to meet these challenges. Another observable outcome is in the development of the key skills of communication, group work, critical analysis, and the ability to explain their point of view and contest their position.

Evaluation

The PBL physics course described here has been and is continually being evaluated. The evaluation is divided into:

- comparison with a traditional lecture-based course;
- evaluation by an independent external evaluator;
- comparative assessment of the retention of knowledge into their second year of study for PBL and non-PBL students; and
- student evaluation and feedback.

Our evaluation to date has shown that the PBL students exceed non-PBL students in their understanding of physics concepts, achievement in standard physics tests, development of key skills, and ability to work in groups. The PBL students are also more motivated, have a 100% class retention rate as compared with 66% for the non-PBL students, and are more willing to interact with the teaching staff. They found the PBL course to be fun, interesting, challenging and motivating and wondered why problem-based learning was not used more extensively. The main problems they have are related to the group work and their lack of experience of working in groups. They are unsure what to do when conflict arises or when a student has not carried out assigned tasks. This is where it is important for the tutor to help the students overcome these problems by developing their skills at group work. It should be noted here that first-year students find self-assessment very

difficult initially, but, again, as they adapt to group learning it becomes easier. This type of assessment should not be introduced at the start of the course but later, when the students have developed the ability to evaluate their role in the group and the performance of others.

CONCLUSION

The major advantages of problem-based learning courses are that the students develop the ability to learn independently and in groups, and develop key skills and the ability to contest and debate. It helps the students acquire ownership of their learning experiences by giving them control of

the learning process. By learning in this way, the students become motivated self-directed learners. It also offers the students the chance to engage with real-life problems and helps them see the ambiguity that may exist in real-life situations. It develops a sound understanding of the knowledge and the ability to critique information. It allows the students to make sense of the material in their own way by integrating newly acquired knowledge with prior knowledge and experiences. Although PBL involves a major transition in the students' learning experience, we have shown that it is possible to successfully design and deliver a first-year physics PBL course so that this transition is managed so as to motivate the students to become self-directed learners.

REFERENCES

1. F. Marton and R. Saljo, Approaches to learning, in F. Marton, D. Hounsell and N. J. Entwistle (eds.), *The Experience of Learning*, Scottish Academic Press, Edinburgh (1984).
2. D. Boud and G. Feletti (eds.), *The Challenges of Problem Based Learning*, Kogan Page, London (1997).
3. D. Kolb, *Experiential Learning*, Prentice-Hall, Englewood Cliffs, New Jersey (1984).
4. J. Dewey, *Experience and Education*, Collier and Kappa Delta Pi, New York (1938).
5. C. Engel, Not just a method but a way of learning, in D. Boud and G. Felitti (eds.), *The Challenge of Problem Based Learning*, Kogan Page, London (1997).
6. H. S. Barrows and R. M. Tamblyn, *Problem-Based Learning: An Approach to Medical Education*, Springer, New York (1980).
7. H. S. Barrows, A taxonomy of problem-based learning methods, *Medical Education*, **20** (1986), 481–486.
8. M. Savin-Baden, *Problem-Based Learning in Higher Education: Untold Stories*, Open University Press/SRHE, Buckingham (2000).
9. P. Cawley, A problem-based module in mechanical engineering, in D. Boud and G. Feletti (eds.), *The Challenge of Problem Based Learning*, Kogan Page, London (1997).
10. D. H. Dolmans and H. G. Schmidt, What drives the student in problem-based learning?, *Medical Education*, **28**(5) (1994), pp. 372–380.
11. C. M. L. Miller and M. Parlett, *Up to the Mark: A Study of the Examination Game: Changing University?*, Open University Press/SRHE Buckingham (1974).
12. L. Taylor and H. Burgees, Orientation to self-directed learning: paradox or transition process, *Studies in Higher Education*, **20**(1) (1995), pp. 87–97.
13. W. H. Gijsselaers, Connecting problem-based practices with educational theory, *New Directions for Teaching and Learning*, **68** (1996), pp. 13–21.
14. L. Taylor and H. Burgees, Orientation to self-directed learning: paradox or transition process, *Studies in Higher Education*, **20**(1) (1995), pp. 87–97.

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