

A review of Problem-Based Learning applied to Engineering

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Abstract

This study examines the theoretical foundations of the teaching method known as Problem-Based Learning (PBL). We discuss the origins of the approach and its application to the field of engineering education, and also provide a number of basic guidelines. Practical aspects concerning the design and implementation of PBL are considered, along with various studies into its use with the technical sciences. Finally, we report on research into the adoption of PBL for the teaching of engineering courses during the academic years 2013-14 and 2014-15 at the School of Engineering of the University of Huelva.

Keywords

Problem-based learning; PBL; Engineering education; teaching methods.

1. Introduction



Problem-Based Learning (henceforth PBL) is a methodological approach to teaching in which learners solve problems of varying degrees of complexity (frequently based on actual cases) using any resources they think may be of use. The pioneers of PBL in medicine, Barrows and Tamblyn (1980), define the approach as “the learning that results from the process of working toward an understanding or resolution of a problem” (p1). Although PBL has its origins in the training given those studying for legal practice in the English-speaking world (and not medicine, as widely believed), the authors credit the teaching programme devised by the School of Medicine at McMaster University in Canada in the 60s and 70s with its first application to the sciences. Since then, PBL has been adapted to many different areas of study, including the various branches of engineering and architecture. Although these adaptations have seen considerable variation from the original model, the essential features of the McMaster programme have been retained. These guiding principles, as applied to engineering, are discussed in the following section. Of influence in this respect is the work of Yadav et al. (2011), although the actual framework for discussion offered below is of the authors’ own devising. It should be noted, however, that applied to the field of architecture, the underlying principles of PBL require a certain degree of adaptation by specialists, given that a central feature of the training within the discipline is the architectural project, which demands a comparable, but significantly different methodological approach. In the discussion of engineering, the chief sources of data are the observations and experiences collated from the Construction Engineering courses at the University of Huelva during the academic years 2013-14 and 2014-15.

2. Applying PBL: essential features for engineering education

2.1 Learner-centred teaching

Students should take responsibility for their own learning under the guidance of a tutor who takes on the role of consultant. The areas about which the consultant advises include, but are not limited to, identifying the essential features of the problem in question to enable the students to fully grasp it and take an suitable approach, and directing students to appropriate



sources of information, such as books, journals, engineering projects, technical legislation, teachers, and internet resources. The aim is for the learning to centre on the specific skills and knowledge required to solve the problem in question, and for these to be tailored to the student.

2.2. Small groups

In the field of the sciences, work groups comprise from 5 to 8 students, whilst we recommend just 3 or 4 in the area of engineering. Once each teaching module is finished, groups are randomly reconfigured so that students learn to work productively with different people.

2.3. Teacher as facilitator

The teacher takes on the role of facilitator or tutor, challenging the students to question their thinking and to find the best approach towards understanding and resolving the problem. As the course progresses, the students become able to take on this role themselves and make the same demands of each other.

2.4. Generating appropriate problems lies at the core of learning and developing organisational skills

For the disciplines concerned, PBL presents students with a problem, which is structured according to a given format, such as a case-study. An example would be the design and execution of a retaining wall to well-defined structural specifications. The objective is to set a task which faithfully reproduces the kind of challenge the students are likely to meet in practice, so that the work is seen to be relevant and is infused with an intrinsic motivation. In order to gain an understanding of the problem in hand, students need to identify the areas of applied knowledge which they will need to study within the technological sciences. The required information is drawn from various disciplines, and is likewise applicable to similar problems in other subjects, such as Structural Theory or



Geotechnical Engineering. The desired outcome is to make it more likely that the student retains what he or she has learned and is able to apply it in the future.

2.5. Developing skills through problems

So far as possible, problems for the engineering disciplines should derive from real life or be a very close representation of it, involving the kind of applications which the students are likely to meet in the context of their future professional lives. For example, the basic legislation governing the use of reinforced concrete is largely standardised; likewise, the components and properties of each kind of concrete are well-defined. Nevertheless, the way in which these are used in actual situations vary according to the kind of problems specific to each specialism, whether building an irrigation canal or reinforcing tunnels for mining. There is wide variation in terms of both the construction procedures to be followed and the best available solutions. Hence, the problems themselves adopt specific features appropriate to the branch of engineering in question, whilst the underlying scientific and technological basis is largely the same.

2.6. Self-directed learning as a means to new knowledge

Lastly, students are expected to learn from their understanding of real world situations and the accumulation of experience, by means of their own study and research, and the information supplied by the experience of previous authors. In the course of this phase of self-directed study, the students work together, constantly discussing, comparing, and reviewing what they have learnt. This is the most important aspect of PBL for the future engineers, not only because it is a highly effective means of improving their performance in problem-solving, but it also undoubtedly ensures the development of professional competences.

3. Applying PBL: key specifications



Medina, Rivilla and Domínguez and Garrido (2009) affirm that PBL has a specific methodology which differs significantly from traditional or conventional methods of teaching. This means that teachers, whatever their personal aims regarding the course in question, need to have a sound grasp of the underlying principles in order to apply it properly, or else risk turning classes which meet official educational guidelines into a directionless potpourri. In this respect, it is worth remarking that official Teacher Training programmes treat PBL as a recognized approach that prospective teachers should be aware of. Although it is an approach which is particularly amenable to the sciences, it has largely been within certain fields (notably medicine and engineering), and at university level, that it has been most successfully put into practice. Various authors across a range of knowledge areas have lamented shortcomings in the training available for PBL. Aware of this and the relatively limited literature to be found, they put together a collection of studies into a book, which sets out the key features of PBL as a kind of teaching guide (for further information, see the bibliographic references). Given the relatively recent adoption of PBL in degree courses (beginning with medicine in the 60s and much later engineering well into the 90s), a collection of basic texts drawing together our accumulated understanding of the approach would be very welcome. The following section discusses various studies into the use of PBL with specific groups. The aim is not to provide an exhaustive analysis, but rather to give a sufficient overview for the reader to appreciate the difficulty of applying the methodology to training in the technical sciences.

3.1. Designing and implementing PBL

This sub-section has particular relevance to practical considerations, as it draws together information from various studies oriented towards evaluation of the use of PBL. The section opens with discussion of two doctoral theses from the Proquest database, dealing with training in the fields of medicine and nursing. These studies are strongly indicative of the wealth of data available within the area of the health sciences with regard to assessing the implementation of PBL in terms of both its theory and practice. The experience with PBL that has been accumulated by medical and nursing faculties since the 60s means there is an abundance of empirical studies into both the practical application of PBL and the



different methodologies employed in evaluating its effectiveness. Caution should be exercised when it comes to transferring the premises of researchers in the health sciences to the field of engineering, as the teaching content and context are clearly not the same, but there is nevertheless much of value that survives the passage. For example, Oldenburg's (2008) thesis, carried out in the area of health sciences but equally applicable in focus to the technological sciences, concludes after considerable research that a necessary condition for the successful implementation of PBL is supervision on the part of the teacher and physical presence on the part of the students. The work confirms the hypothesis that without a teacher, PBL cannot take place, irrespective of the use of ICT. In short, PBL requires total supervision by a physically present tutor. For his part, Applin (2008) discusses the findings of a study into PBL at a nursing faculty in Canada. Particular emphasis is given to the demands put upon training in terms of time by PBL and non-PBL programmes. The PBL-based courses are demanding, and there are Canadian universities which employ PBL across the entire nursing curriculum, or very nearly so, with the result that nursing students from the Alberta study and other areas of Canada, often include on their CVs the fact of having received their training via this methodology.

Elsewhere, Fernández Martínez (2008) focuses her doctoral thesis on the promotion of quality in university level teaching and learning, with an emphasis on advancing the process of European convergence. The study undertakes a systematic evaluation of university methodologies and provides support for training approaches which are more innovative and consistent with the principles of the European Higher Education Area (EHEA) and the demands of modern, knowledge-based society, such as is the case with PBL. The study uses a qualitative methodology, whilst the literature review and theoretical framework (in the context of EHEA) are highly relevant to the study of PBL.

Bernabeu Tamayo (2009) sets out to describe the efforts of various groups in an institutional context to bring about changes to the curriculum. The opening section provides a theoretical review of the fundamentals and key contributions to the topic, whilst the following section considers the practical aspects, exploring features of the culture of change in centres and groups based at Catalonian universities which have implemented problem-based learning and project-based learning approaches. Although the system of



evaluation is different to that employed in the study carried out at the University of Huelva (viz. a quantitative quasi-experimental system), the theoretical section contains a valuable literature review. Whilst the two doctoral theses discussed above include reviews of highly relevant studies, neither adopts an experimental or quasi-experimental approach to evaluation, which, in our opinion, is preferable in the case of the technical sciences.

A topic of special interest to the design and implementation of PBL is that of individual and group work on the part of the student. In this respect, Posada Álvarez (2004) examines higher education in terms of competences, interdisciplinary approaches and individual work, whilst Bernaza Rodríguez (2005), by contrast, considers collaborative learning. Both, that is individual and group work, are in our opinion indispensable for designing and putting into practice PBL in an institution based on a term or semester cycle. Without any individual work, it is difficult to see how the student will assimilate the knowledge required for the sessions involving complex PBL; without the collaborative work (meant literally, rather than merely work in groups) there would be no practice in developing the communicative skills necessary for negotiating the problems set for the group to solve. The lack of time should be compensated for by a significant amount of individual work, supported by an appropriate online platform.

3.2. PBL and technical subjects

On the question of which methodologies might be appropriate to the technical sciences, the realm of art and design has been considered by various authors, such as Groenendijk, Janssen and Rijlaarsdam and van den Bergh (2013). This study, on the effect of observing peers doing tasks on learning outcomes, provides two areas of interest for research into PBL. The first is creativity in the design process, which was found to be enhanced by observation, and associated with increased brainstorming. The second is the experimental design itself, which followed a pre-test, post-test structure (ibid. p. 35) and is explained in detail in the paper, although it must be said that the teaching methodology employed in the experiment is not strictly PBL, but rather an alternative approach sympathetic to its principles. In this respect, the paper by Yadav et al. (2011) is probably the most relevant of



those included in the bibliography, and it is duly given fuller treatment here. The paper begins by usefully providing some background information about teaching methods at undergraduate level, charting the development from lecture-based teaching to more student-focused methods, such as PBL. It notes that research into these approaches has tended to be anecdotal rather empirical, and so aims to provide a data-driven analysis. The aim of the study was to evaluate the impact of PBL on the conceptual understanding of fifty-five students enrolled on an undergraduate course in electrical engineering at a Midwestern university in the USA. The researchers used an A-B-A-B design, comprising a baseline phase of traditional, lecture-based teaching followed by an experimental phase of PBL, and incorporating pre- and post-testing of the students on the four topics covered during the course of the study. Students also completed a ‘Student Assessment of Learning Gains’ questionnaire, which registered participants’ perceptions of the two methodologies employed. The test results demonstrated a clear advantage of PBL over the lecture-based approach in terms of learning gains. Curiously, however, the students’ own perceptions were that they had learned more in the lecture-based classes, a fact of considerable significance to faculty considering the implementation of PBL. The authors conclude that, given the scarcity of research into the beneficial effects of PBL on learning outcomes, the study provides valuable empirical support for its adoption. Also, in view of the counterfactual student perceptions, they offer some specific considerations for university teachers and researchers interested in pursuing PBL applied to courses in engineering (ibid. p280). Within the field of research into PBL, the article is valuable for its account of a specific instance of its application to engineering as well as its evaluation of the method through empirical analysis.

4. Implementing PBL: case study findings at the University of Huelva

This study was carried out within the ambit of a research project into the effects of PBL on student learning in comparison with more traditional teaching methods in courses pertaining to Construction Engineering at the University of Huelva. A quantitative study



was undertaken during the academic year 2013-14 with the aim of identifying whether any significant differences were obtained (Rodríguez, 2014), and the following year (2014-15) individual interviews were added to the study, along with other data sources which are still at the analytical stage. The sample, from which both the quantitative and qualitative data were drawn, was composed of students from various courses within Construction Engineering, some of whom received instruction through PBL whilst the rest were taught using the habitual methodology. The findings of the study are summarized below:

1. Significant differences were found in the learning gains between students participating in teaching programmes featuring PBL and those in programmes featuring traditional modes of teaching.
2. Analysis of the objective tests showed that there had been an improvement in the approaches to solving the problems set in the tests.
3. PBL represents an effective and more efficient teaching method than the alternative, which combined lectures with exposition of problems by the teacher.
4. There was a reduction in calculation errors deriving from misapplication of mathematical procedures or from incorrect use of calculators.
5. Students in the groups receiving PBL tended to show greater creativity in their approach to solving problems. The openness to new ways of tackling problems is one of the distinct advantages which PBL offers over more traditional teaching methods in the engineering subjects.
6. The qualitative information underlined the importance of the teacher-tutor's personality and leadership qualities. In like fashion, the corollary for the teacher using PBL to have a thorough grounding in the methodology can also be emphasized.

Over the course of the academic year 2013-14, an increase in students' academic performance as a result of PBL was recorded. The number of passing grades that were

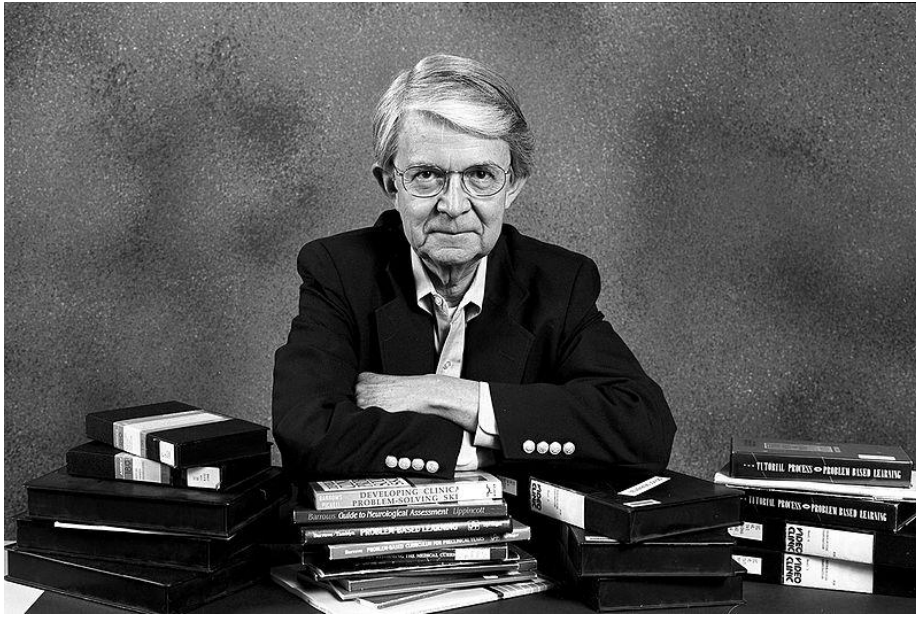


awarded increased considerably, and the average grade increased by over 30% (Rodríguez, 2014). The evaluation of PBL in engineering education requires objective measures, but this study has also been shown that the use of qualitative forms of data collection can provide other kinds of relevant information to be taken into account. In order to do so, the authors are currently developing a mixed methodology for evaluating the use of PBL in engineering education.

5. Conclusions

From a historical perspective, there is no doubt that PBL has been most widely adopted in the field of medicine, largely through the work of Professor Howard S. Burrows (see photograph below) and his colleagues. However, its implementation in the technical sciences has been somewhat slower. The difficulty inherent to training in engineering and architecture, no easy subjects to teach and learn, along with the knowledge of scientific principles they demand, make it a tall order to implement PBL in official courses within the span of a semester (let alone a single term). Careful planning and organisation are necessary. Teacher-training in PBL and gradual exposure to its implementation can benefit from the availability of guidelines to follow. The researchers covered in the literature review and included in the bibliography offer a careful selection of material suitable for studying the theory of PBL. The observations provided in this paper can also be of use to those practitioners of training in the technical sciences who would like to know more about alternative methodologies. In the opinion of the authors, if there is a field which is innately appropriate to the development of PBL, then it is specifically that of training in the technical sciences, encompassing engineering and architecture. Given the experiences accumulated in recent years by the authors at the University of Huelva, all efforts one might expend in such an endeavour will not go unrewarded.





Photograph. Howard S. Barrows (1928 –2011). Pioneer of Problem-Based Learning. Southern Illinois University School of Medicine. Source: Portrait of Howard S. Barrows by James R. Hawker (2011). [CC BY-SA 3.0](https://creativecommons.org/licenses/by-sa/3.0/) (Free to share and adapt).



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