View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Universiti Teknologi Malaysia Institutional Repository

Conference on Engineering Education, Kuala Lumpur, 14-15 Dis. 2004.

A review and survey of Problem-Based Learning application in Engineering Education

Mohd Ariffin Abu Hassan[1], Khairiyah Mohd. Yusof[1], Mohd. Kamaruddin Abd. Hamid[1], Mimi Haryani Hassim[1], Azila Abd. Aziz[1], and Syed Ahmad Helmi Syed Hassan[2]

[1]Department of Chemical Engineering,
Faculty of Chemical & Natural Resources Engineering,
Universiti Teknologi Malaysia,
81310 UTM Skudai, Johor, Malaysia.

[2]Faculty of Mechanical Engineering,
Universiti Teknologi Malaysia,
81310 UTM Skudai, Johor, Malaysia.

Abstract - This paper gives a review of Problem-Based Learning (PBL) applied in engineering courses worldwide, and a survey of academic staff who have implemented PBL in engineering classes in Universiti Teknologi Malaysia. The review of PBL application illustrates the extent of acceptance and success of PBL in schools of engineering in the international arena. The survey, on the other hand, illustrates the acceptance of PBL among engineering lecturers and the possibility of applying PBL in Malaysia. The main purpose of the survey is to obtain feedback on PBL regarding the impressions, set-backs and constraints faced, as well as innovations and tips for successful implementation from the faculty members involved.
Keywords: Problem-Based Learning; Engineering Education

1.0 Introduction

Problem-based learning (PBL) is seen by Barrows and Kelson [1] as a total approach to education, both a curriculum and a process, where the curriculum comprises 'carefully selected and designed problems that demand from the learner acquisition of critical knowledge, problem solving proficiency, self-directed learning strategies, and team participation skills' and where the process 'replicates the commonly used systemic approach to resolving problems or meeting challenges that are encountered in life and career.' Other authors [2,3] define problem-based learning as a way of conceptualizing and constructing curriculum or, alternatively, as a system of instructional design and practice. It is recognized that 'real-world' problems serve as a stimulus for student activity, promoting the development of skills of critical thinking and problem solving. Additionally, acquisition of the knowledge of the essential concepts of the learning area and the application of knowledge and skills within the arena of professional practice, are integral to the definitions.

A useful definition from Finkle and Torp [4], elaborated by the team from the Center for Problem-Based Learning, Illinois Mathematics and Science Academy at http://www.imsa.edu/team/cpbl/whatis/whatis/slide6.html suggests that problem-based learning is a development and instructional approach built around an ill-structured problem which: i) Is messy and complex in nature; ii) Requires inquiry, information-gathering, and reflection; iii) Is changing and tentative; iv) Has no simple, fixed, formulaic, "right" solution.

1.1 What is Problem Based Learning (PBL)?

Problem Based Learning is a curriculum development and delivery system that recognizes the need to develop problem solving skills as well as the necessity of helping students to acquire necessary knowledge and skills. Indeed, the first application of PBL was in medical schools which rigorously test the knowledge base of graduates [4]. PBL utilizes real world problems, not hypothetical case studies with neat, convergent outcomes. It is in the process of struggling with actual problems that students learn both content and critical thinking skills. Problem based learning thus has several distinct characteristics which may be identified and utilized in designing such curriculum. These are:

a) Reliance on problems to drive the curriculum - the problems do not test skills; they assist in development of the skills themselves.
b) The problems are truly ill-structured - there is not meant to be one solution, and as new information is gathered in a reiterative process, perception of the problem, and thus the solution, changes.

c) Students solve the problems - teachers are coaches and facilitators.
d) Students are only given guidelines for how to approach problems - there is no one formula for student approaches to the problem.
e) Authentic, performance based assessment - is a seamless part and end of the instruction.

The typical characteristics or features of PBL are described in Table 1 [4].

Table 1. Typical Features of the PBL Method

Problems are designed to emulate real-world problems.
Problems used are complex and cover multiple objectives.
The problem or task is introduced FIRST, before any learning occurs.
Learning procedures, facts, and concepts occurs within the context of finding a solution to the problem.
Specific procedures or algorithms are learned as needed.
Additional structure for learning is proportional to the experience level of the learner.
Much of the structure for learning is provided through in-depth questioning by the instructor.
Students using this process usually work in cooperative or collaborative groups to gain multiple perspectives on possible solutions.

Effective problem-based learning methods do not rely on students to follow the process described above without direction and support. Tutors provide guidance and direction by working closely with each small group during the problem identification, learning issues definition, and reflection activities. An important characteristic of the tutor's role is its emphasis on the processes rather than the subject matter content necessary to address the problem. The tutor's primary role must be guiding students through the use of metacognitive skills needed for the problem at hand and for future practice. "This concept of metacognitive thinking skills provides the key to the positive, active role of the tutor" [5]. Obviously, tutors must be skilled in both the PBL process as well as reasoning skills. The following section briefly reviews the application of PBL in engineering courses worldwide.

2.0 PBL in engineering courses worldwide

Engineering education is under increasing pressure for change. Traditionally taught by lectures supplemented with tutorials (numerical problem solving) and practical (laboratory) classes it has always been content driven with staff enforcing rigid course objectives. Both academic staff and students have implicitly held the main objective of a subject to be the ability to pass the examination. These engineering courses ensure technical competent graduates who have successfully met the responsibilities of the profession to provide goods and services to society. Subsequent development of other professional attributes relevant to communication and teamwork has been accepted as a responsibility of employers, and depended on the developing maturity of the individual. The breadth of professional knowledge has now grown to the point where no student can master all of the discipline knowledge in a four to five year period. Students are also increasingly being criticized for their lack of complementary skills. As a result, the profession and universities around the world are increasingly looking to instill life-long learning skills rather then technical content. Progressive universities are starting to re-structure their courses to meet these new expectations. Problem-Based Learning becomes an attractive vehicle for such changes.

2.1 PBL in UK

PBL being implemented since 1998 in Chemical Engineering course as well as Electrical & Electronic Engineering courses at three universities which are University of College London (UCL), The University of Bristol and University of Manchester Institute of Science and Technology (UMIST) [6]. The method involves the development of knowledge and key skills through a series of carefully planned problems, solved in small groups. It is expected that the graduates from PBL courses will be equipped with the skills needed to perform as leaders in industry and will be better able to anticipate problems early in the life-cycle of a project and be able to establish solutions. To ensure the implementation of PBL is successful, GBP 180,000 has been allocated by the three universities with GBP 252,000 from the Higher Education Funding Council for England (HEFCE). This enables the three universities to develop and introduce PBL into a wide range of modules in their MEng and BEng (Hons) programmes.

In September 2001, PBL was introduced as the primary teaching method for undergraduate engineering programmes at the University of Manchester. The focus of PBL is to organise the curricular content around problem scenarios rather than subjects or disciplines. Students work in groups or teams to solve or manage these situations but they are not expected to acquire a predetermined series of 'right answers'. Instead they are expected to engage with the complex situation presented to them and decide what information they need to learn and what skills they need to gain in order to manage the situation effectively. This radical approach was chosen in order to address: i) The changing skill base of University entrants, including lack of numeracy/ literacy; ii) The needs of industry for graduates with not only a solid foundation of engineering knowledge but also good communication skills, the ability to work in a team and solve problems. The introduction of PBL brought many benefits and rewards for staff and students and also raised a number of challenges. Observations from staff indicate that after completing the first year of PBL, the students are more confident of their own abilities, better able to work in a team, keener to learn and have a greater understanding of the practical aspects of engineering. It is anticipated that the programmes will produce motivated, enthusiastic students who are familiar with the roles and responsibilities of professional engineers. This method of teaching also resulted in decreased re-sits and end of year failures, progression from year 1 improved from 75% to 86% in the first year of PBL, which has a clear positive impact on retention rates. The adoption of PBL has also had a significant impact on the conversion rate of applicants to firm acceptances within the UCAS system.

The reception by industry, professional institutions, students and parents has been uniformly positive and described as 'unique' and 'innovative'. There are other universities in the UK that widely use PBL in engineering courses [6]. These include Coventry University, Imperial College, University of London and University of Strathclyde. Thus it can be seen that experimentation around the use of problem-based learning in the UK has therefore been shaped by new questions being raised about professional education in the context of unprecedented world expansion in higher education. Change in the UK appeared to have emerged as a result of the government's growing demand for greater accountability within education and employers' preferences for graduate entrants with key skills. PBL is seen to offer opportunities to call for the end of knowledge, disciplines and staff student boundaries, an end befitting a fragmented, ambiguous post modernity.

2.2 PBL in Australia

At Monash University, PBL has been introduced to several courses in the civil engineering degree, including Systems Engineering, Surface Water Modelling and Civil Engineering Computer Applications [7]. Some of other applications of PBL in engineering that have been reported include course in Mechatronic Engineering at Curtin University, Western Australia and Water and Wastewater Engineering in Civil Engineering at Griffith University, Queensland [8]. Within the examples of PBL, the evaluations that have been undertaken have been almost entirely along the lines of student interviews or responses to open-ended questions. This qualitative research has generally found students in favour of the courses, where they have been sufficiently prepared for the PBL environment.

In early 2000, the Faculty of Engineering and Surveying, The University of Southern Queensland (USQ) embarked on a major review and restructure of its programs to prepare for re-accreditation and to ensure that the Faculty's teaching was in accord with Best Practice [9]. The review process established that some major changes were required to develop attributes relating to teamwork, problem solving ability and life-long learning patterns. Proposed changes to the programs of study included the removal of some traditionally taught, content based and their place was to be taken by newly developed strand of so-called PBL. From their PBL experiences, the USQ engineering students found that learning was more interesting and engaging, and that they developed a greater understanding of engineering science and core engineering fundamentals because they found the information for themselves and actively used the information to complete their projects.

2.3 PBL in United States and Canada

The use of PBL in engineering programs in United States has been reported by several authors, although the practice is still far from widespread. One of the more well known applications has been by Don Woods in the Chemical Engineering program at McMaster University and has been described in several publications [7-10]. With a strong tradition of PBL already developed in medicine at the same university, the department of Chemical Engineering decided to implement it in their program in the early 1980's. Research has been done to the PBL at McMaster University. It was found that PBL students have gained better insight into what to expect from their profession and what kind of knowledge will possibly be needed. Additionally, by learning the theory component in the context of a real-life problem, the PBL students had better developed the cognitive structures that are needed to retrieve this information for its future use and application in the workplace.

The Aeronautics and Astronautics Department at Massachusetts Institute of Technology (MIT) implemented a PBL curriculum in 1997 [11]. PBL and design-build experiences were integrated across the undergraduate aerospace programs at MIT. Design-build experiences are sequenced from more simple projects to highly complex systems. In these PBL experiences, MIT students found that learning was more interesting. Through self-assessment and colleague assessment activities, students were able to monitor their own learning, assess their progress, and evaluate their own and their colleagues' contributions to the success of the projects. Moreover, with an emphasis on learning in real-world contexts, students see the connections between the subject matter and their own professional interests. Others universities include University of California Irvine (School of Engineering) and University Of Minnesota (Civil Engineering).

2.4 PBL worldwide

Aalborg University in Denmark implemented a PBL curriculum in 1974 [12]. A large-scale evaluation of PBL was undertaken utilizing questionnaires to study the reactions of students, employers, graduates and external examiners. It was noted that students:

i) Chose to go to Aalborg because of PBL
ii) Are enthusiastic about group work
iii) Felt PBL prepared them for graduation
iv) Felt better prepared in management, cooperation, problem-solving, teamwork, and general technical knowledge [12]

Other universities across the world do have courses in their engineering programmes that are conducted with a PBL approach. These include Temasek Polytechnic and the Republic Polytechnic in Singapore. Both have completely PBL curricula for computer, electrical and industrial systems engineering diploma programmes [13-14]. PBL is used in Engineering at The Hong Kong Polytechnic University and Engineering Management and Communications at Hong Kong University of Science and Technology. From PBL experiences the students from both universities become more motivated by actively engaging in the learning process and taking responsibility for their own learning. By having greater ownership of the teaching and learning process, students learn how to learn and are much better able to deal with unfamiliar situations. The context of learning is more realistic and there is plenty of anecdotal evidence indicating that graduates from PBL courses are better prepared for the workforce than those from more traditional programmes. In the Faculty of Chemical and Natural Resources Engineering, Universiti Teknologi Malaysia, PBL had been first introduced in 2003 [15]. The first attempt at introducing PBL was for the Process Dynamics and Control subject for the fourth year Chemical Engineering students. That was also the first exposure to PBL for most students. It was found that the students had better understanding of the subject with PBL compared to the traditional lecture delivery approach.

3.0 Questionnaires on PBL

This section describes the feelings and thoughts of lecturers for the implementation of Problem-Based Learning in engineering courses at Universiti Teknologi Malaysia. The questionnaire focuses on three major types of constraints hindering the successful implementation of PBL: resource allocation, student responses to PBL and the challenges to the lecturers associated with enacting and implementing PBL.

4.0 Results and Discussion

To achieve the objectives of PBL in the studying behaviour of students, the lecturers play a very important role and his or her conduct has a great impact on the conduct of the students he or she works with. And as this role is very different from the traditional lecturer role, it is of great importance to know where this task is about and what qualities are required to perform that task properly. Six responses were received from the questionnaires. Although only a small number of responses were obtained, the respondents appear to be well qualified by experience to comment on the factors affecting the implementation of PBL at Universiti Teknologi Malaysia.

4.1 PBL Experience

The lecturers were invited to provide feedback on their experience of implementing PBL with a view to both learning from the experience and offering ideas and suggestions for the future. Topics raised included: (1) what they felt about the experience, (2) how they had gone about conducting the PBL sessions and (3) their evaluation of the approach. The following is a summary of the feedback :-

Content to be covered. The findings from the feedback have produced a varied portrait of what the experience of tutoring was like for these correspondents doing PBL for the first time. They said that it was a good teaching experience for them but some of them seemed unclear about how much content they were to teach when they first read the problem statements. Their concerns were resolved after discussion with the subject lecturer who designed the 'problems' in the first place.

Understanding the purpose of PBL. While the feedback from the questionnaire such as this does not provide conclusive proof, they do provide a picture of perspective in the process of implementing a new focus. It is important to keep in mind that five of the correspondents were the first timers with PBL and they were novices at this type of training. Many of them were willing to take the chances involved in such a new venture. For some, however, there were times of frustration and anxiety. This was to some extent due to lack of clarity about the nature and purpose of PBL. In spite of attempts to clarify the aims of PBL, the message did not get through to all staff or students.

Disfunctioning groups. From the questionnaire, all of the lecturers experienced groups that were not functioning well. In order to tackle this problem they gave an individual counseling to all the members of the groups. Additionally, one of the respondent addressed the disfunctioning groups more often compared to the other groups.

Training of Lecturers. Further training is needed for the lecturers. This is important so that the lecturers have sufficient knowledge to distinguish between fact main points and side issues. What did happen, however, was that the process encouraged students to see themselves as responsible for their learning. Observations suggested that many students felt a real sense of ownership over the content and of the progress. This, in turn, caused most of the lecturers to express respect for the work of the students. Therefore, one might conclude that much of the necessary behavioural change will come through positive experiences of tutoring more than through lecturing. Some of the improvements for ongoing learning of PBL approaches may have to include peer tutoring, feedback from students and discussions with "experts" on what was observed. So in general, training for the lecturers is vital to ensure the objectives of PBL are achieved. This is important in order to sharpen the important skills that the lecturers have to ensure more effective PBL implementation. The important skills are such as questioning, how to react to questions of students, to give feed-back, how to start with a new group and tackling groups which are disfunctioning.

The challenges associated with implementing PBL. Mind sets of the students as well as the lecturers have to be changed. PBL requires students to take on active learning strategies and adopt a self-directed learning disposition. Some students find it difficult to cope when asked to transform into active critical thinkers. PBL lecturers may also face difficulty as they prepare to facilitate discussion, provide coaching, challenge student thinking and manage group work. Below are some challenges that have been found from the respondents.

- **Limited experience in team work management** Team work is integral to PBL and students need to learn how to make optimal use of their time and resources while working in groups. Functioning effectively in groups involves knowing how to organize the work, distribute responsibility, break up complex tasks, and provide useful feedback on work that is done. Lecturers can contribute by helping students better understand the merits of team work, how to work in a team and monitoring.

- **Lack of familiarity with inquiry learning** When faced with problem tasks, students often find it difficult to identify the critical issues and to generate coherent research designs. They are often unclear about how they can relate what they are currently reading to what they already know. They find difficulties in understanding what they read and extracting as well as synthesizing information. Additionally, they are also unfamiliar with different stages of the inquiry process, such as generating hypotheses, providing logical arguments, and transforming data into a product. When students have an appropriate learning context and the need to seek the necessary information, they also see how things finally "come together". This is an aspect of critical reading that can be promoted within the framework of problem-based learning.

- **Frequent feedback on learning and assessment** Giving feedback to students is integral to improving student learning. Lecturers can better guide and monitor problems by incorporating formative self-reflections by students, by creating a culture that supports frequent feedback and assessment, and by finding ways for students to compare their work with others. Lecturers can make students take their work seriously by incorporating opportunities that involve external audiences in assessing students' performance.

The benefits of PBL to the students. Problem-based learning encourages students to take control and become active in their learning. The assessment tasks relate directly to the learning that has occurred and while requiring content knowledge to successfully complete, require a more contextual approach in their design. Since the problem cannot be clearly approached on the first encounter, it becomes a challenge, promoting creative thinking and developing organizational skills to the students. Additionally the legitimacy of the group's as well as the individual's learning goals are established. Besides transfer of knowledge among the students and skills are enhanced through the use of multiple tasks and problem concepts to help form functional abstractions.

The use of problem-based learning in engineering programs has been reported, although the practice is still far from widespread. Although a panel of six practitioners might not be sufficient to sustain claims of statistical significance, it exceeds the minimum size recommended for panels of evaluators in heuristic evaluation methods to ensure identification of 75% of useability problems [16]. From the questionnaire, the results indicate that there are several factors affecting the implementation of PBL for engineering courses at Universiti Teknologi Malaysia. These factors are, namely resource, quality assurance, student factor and teaching belief. To sum up, the questionnaire, which was designed from the themes emerged from the questionnaire in the early phase of this study, confirmed that student factor, teaching conception and qualitative assurance and/or resource support were the basic hurdles affecting PBL implementation for engineering courses at Universiti Teknologi Malaysia.

To alleviate the above problems, the quality assurance/resource and the student factor should be dealt with first. In terms of their nature, these two factors could be classified as internal operational and external. The quality assurance/resource factor (internal operation) includes issues such as appropriate deployment of funding to substantiate staffing (workload, timetable and training). For the teaching conception, it is important for the lecturers to know their role and the proper way to conduct the class. And as this role is very different from the traditional lecturer role, it is of great importance to know where the task is about and which qualities are required to perform that task properly. The main difference with the traditional lecturer is that the lecturer in PBL does not teach, but he or she is a guide who supports the studying and the learning process of his or her students. He or she is not 'the sage on the stage but the guide on the side'. So, how to put PBL in the proper perspective? The anxiety and fear in lecturers should be removed by leading them to understand the true spirit of PBL, by training them to be effective facilitators (as tutors) and lecturers (as resource persons), by providing feedback and guidance to their performance in facilitating learning and handling group dynamics, and by giving them attractive incentives and rewards.

5.0 Conclusion

Any successful innovative teaching methodology has to be supported by positive students' responses. All of the respondents perceived negative student responses toward PBL. Since PBL is only introduced in a few subjects at Universiti Teknologi Malaysia, students are still exposed to traditional teaching methods in other non-PBL subjects. As a consequence, comparison of workload among different courses would create negative feelings as PBL courses usually demand greater workload and more independent learning. Another frustration experienced by the students was their initial inability to integrate the diverse ideas generated by the nature of the problems they were investigating. From the questionnaire, the respondents suggested that it was necessary to constantly reassure and motivate them without actually providing the answers. By challenging their guesses and assumptions the lecturers will gradually able to focus their minds or relevant factors and enable them to reject which only lead only to "blind alleys". Eventually, the students will begin to realize what a powerful tool the lecturers are putting into their hands. In general the lecturers have to work hard to change the student's attitudes. Problem-based learning is an instructional method that uses real world cases or problems as the starting point of learning. In the process, it is envisaged that students will acquire critical thinking and problem-solving skills. Commonly stated benefits of PBL include integration of knowledge; life-long learning; motivation to learn; development of reasoning and critical thinking skills; development of communication and interpersonal skills; development of the ability to work effectively in a team.

6.0 References

[1] http://edaff.siumed.edu/dept/index.htm

[2] Boud, D. and G.I. Feletti, (Eds), The *Challenge of Problem-Based Learning*, 2nd Ed., Kogan Page, London, 1997

[3] Stepien, W. and Gallagher, S., *Problem Based Learning: As authentic as it gets.*, Educational Leadership, 50, 25-28, 1993

[4] Finkle, S.L and Torp, L.L., Center for Problem-Based Learning, Illinois Mathematics and Science Academy at http://www.imsa.edu/team/cpbl/whatis/whatis/slide6.html, 1995

[5] Barrows, H.S., Problem-Based Learning in Medicine and Beyond: A Brief Overview, in Wilkerson, L. and Gijselaers, W.H. (Eds) *Bringing Problem-Based Learning to Higher Education:Theory and Practice, New Directions for Teaching and Learning,* No. 68, Jossey-Bass, San Francisco, CA, 1996

[6] Problem-Based Learning directory, http://interact.bton.ac.uk/pbl/index.php

[7] Northwood, M. D., Northwood, D.O. and Northwood, M. G., *Problem-Based Learning (PBL): From the Health Sciences to Engineering to Value-Added in the Workplace*, Global Journal of Engineering Education, 7(2), 157-164, 2003

[8] Mills, J.E. and Treagust, D. F., *Engineering Education-Is Problem Based or Project-Based Learning The Answer?*, Australasian Journal of Engineering Education, http://www.aaee.com.au/journal/2003/mills_treagust03.pdf

[9] Porter, M.A. and Brodie, L.M., *Challenging Tradition: Incorporating PBL in Engineering Courses at USQ*, The University Of Queensland, 2002

[10] Ward, J.D. and Lee, C.L., *A Review of Problem_Based Learning*, Journal of Family and Consumer Sciences Education, 20(1), 16-26, 2002

[11] Brodeur, D., Young, P.W. and Blair, K. B., *Problem Based Learning in Aerospace Engineering Education*, Proceedings of the 2002 Americal Society for Engineering Education Annual Conference & Exposition, session 2202

[12] Kjersdam, F. and Enemark, S., *Evaluation of the Aalborg Experiment* (1994), http://www.auc.dk/fak-tekn/aalborg/engelsk/evaluation.htm

[13] Temasek Engineering School, *Problem Based Learning*, http://www.eng.tp.edu.sg/tpeng/cen/pbl.xml

[14] O'Grady, G. (Ed.), Reflections on PBL (2002), http://www.rp.edu.sg/pbl/rpnewsletter_issue1.pdf

[15] Khairiyah, M.Y, Mimi Haryani, H. and Azila, N.M.A, *A First Attempt at Problem Based Learning in Process Dynamics and Control Course for Chemical Engineering Undergraduates at Universiti Teknologi Malaysia*, Proceedings of the 2004 The Fifth Asia Pacific Conference on Problem-Based Learning: Pursuit of Excellent in Education, Petaling jaya, Selangor

[16] Nielsen, J., Heuristic Evaluation. In J. Nielsen & R.L. Mack (Eds.), *Usability Inspection Methods* (pp. 25-62), New York: John Wiley & Sons