Problem-Based Learning (PBL) and Project-Based Learning (PjBL) in engineering education: a comparison

Muhammad Khair NOORDIN
Universiti Teknologi Malaysia
Skudai, Johor, Malaysia
mdkhair@utm.my

Ahmad Nabil MD. NASIR
Universiti Teknologi Malaysia
Skudai, Johor, Malaysia
ahmadnabil@utm.my

Dayana Farzeeha ALI
Universiti Teknologi Malaysia
Skudai, Johor, Malaysia
dayanafarzeeha@utm.my

Mohd Safarin NORDIN
Universiti Teknologi Malaysia
Skudai, Johor, Malaysia
p-safarin@utm.my

ABSTRACT

Engineering education nowadays needs to evolve in order to produce marketable engineering graduates. Traditional methods alone do not seem to be able to cultivate required skills by the industries since the demand of the industries on the graduates' skill keeps on changing from time to time. Active learning such as Problem-Based Learning and Project-Based Learning which are based on constructivist learning theory seem the best methods to resolve this issue. Both of these approaches share a lot of similarities, yet there are differences that need to be considered. The purpose of this paper is to seek the differences and determine the best method that is effective and suitable to be implemented in engineering education. PjBL seems more suitable for engineering education compared to PBL because it can give early exposure to the engineering students regarding engineers' job in their industries. In addition, the project works provide them with valuable experience and they can experience working as an engineer.

Keywords: *engineering education, Project-Based Learning, Problem-Based Learning*

INTRODUCTION

Technology is a product and outcome of engineering and science. It is also the application of the knowledge of humans by manipulating and modifying nature to meet their needs. These changes can be achieved by transforming and improving the usage of tools, materials and techniques that have their effect on humans and other living things. Today's technology would not be the same as yesterday's and would not be different than tomorrow's. Every single day, there will be some improvements in technology that most likely affect the engineering industries (Raymond and Albert, 2009). Thus, the demand and requirement of the industries on engineering graduates also keep changing because they are not only seeking those who are technically skilled, but also those who possess non-technical skills as well, thus making them marketable graduates (Low, 2006; Lee, 2003; Kumar and Hsiao, 2007; Woodward, Sendall, and Ceccucci, 2010). Engineering graduates nowadays are expected to possess both skills in order to survive in the workforce. According to Sai et al. (2005), success cannot be guaranteed solely depends on engineering and science knowledge. Thus, non-technical skills become complementary to the technical skills. In other words, both skills are a complete set of skills that must be possessed by engineering graduates. Nonetheless, these skills are unable to be developed by solely depending on traditional methods, which are by listening to the lectures and doing laboratory work.

Traditional methods only provides theoretical, technical and fundamental knowledge of engineering (Abdul Rahman, Suhaimi and Khairul Anuar 2004; Kumar et al., 2007). Engineering education in Malaysia needs to be reviewed and reassessed and the effective ways to improve teaching and learning systems are to be found for cultivating the skills required by industries nowadays. According to Nor, Rajab and Ismail (2008), soft skills and professional practices should be included in the new engineering education model rather than just technical knowledge for future challenges. Teacher centered education that is being used by traditional methods seems irrelevant and thus must be changed to student centered learning with more emphasis on active learning or participation of the students that will drive the learning activities. In engineering education, there are two popular approaches that are being used and implemented in universities around the world in order to produce versatile and marketable engineering graduates namely Problem-Based Learning (PBL) and Project-Based Learning (PjBL). This statement was supported by Kolmos (2009), who mentioned that the solution for the new requirement of skills of undergraduates in engineering education is by implementing Problem-Based Learning (PBL) or Project-Based Learning (PjBL). These two approaches of learning had been confusing and people misjudge both methods as the same thing. The fact is, both are two different things although they share a lot of similarities.

PROBLEM-BASED LEARNING (PBL) IN ENGINEERING EDUCATION

Problem-Based Learning or PBL is a well-known approach among students, educators and researchers. PBL approach which had been introduced by Howard Barrows is an innovative teaching strategy where the teaching manner is shifted from teacher driven to student driven by emphasizing the development of problem solving, creativity and critical thinking skills (Hasna, 2009). PBL is defined as "the learning which results from the process of working towards the understanding of, or resolution of, a problem" (Barrows & Tamblyn, 1980). For Tan (2003), a current definition of PBL is defined as "a progressive active learning and learner-centred approach where unstructured problems are used as the starting point and anchor for the learning process". As the name implies, PBL begins with a problem and that problem becomes the main focus in PBL from which all progress, plan and work done by the students is directed towards solving the problems. PBL was firstly introduced in medical courses in 1969 and it was implemented in McMaster University, Canada and it is now being widely used all over the world. According to Subramaniam (2006), PBL accommodates the environments that encourage the staff's reflection on their personal approach as educators and supports the student learning process. PBL is an innovative learning approach that is based on constructivism learning theory where the learning process is driven by the students.

As PBL has shown its effectiveness, this approach has later being accepted and adopted by various disciplines such as business, mathematics, psychology and engineering as well. There are many ways to implement PBL in the learning process (Duch, 2001). For instance, PBL approach can be implemented by utilizing e-learning (Zaidatun et al., 2005). PBL approach needs to be modified in order to make sure it is appropriate for particular disciplines. The learning process depends on the educators, and how they want to structure the whole model of PBL approach. In 1992, PBL approach in engineering education began with the implementation in undergraduate instruction in both introductory and advanced courses in a few subjects by some professors in the University of Delaware that seemed effective and easy to be implemented in engineering education (Helerea et al., 2008). Nowadays, many universities worldwide have adopted and implemented the PBL approach in their teaching and learning process for engineering subject. Most of the research on PBL for engineering education in Malaysia started around 2004. From all the research, learning outcomes have been successfully achieved by implementing the PBL approach in the teaching and learning process. Researchers all over the world have proven that the PBL approach is much better than traditional approach because it produces better and well-equipped students.

According to A. Ahmad (2006), the achievement of students from the PBL method in examinations, which is mostly paper-based, is as good as the students from the traditional methods, and yet they are better in the practical and hands-on activities. On the other hand, Khairiyah et al. (2005) have proven that students'

generic skills also can be improved through PBL. A comparative study conducted by Hsieh and Knight (2008) on first year engineering students in the University of the Pacific has proved that PBL is an effective method to bridge the gap between practice and theory. Furthermore, PBL provides higher motivation over the traditional approach.

PROJECT-BASED LEARNING (PjBL) IN ENGINEERING EDUCATION

Project-Based Learning (PjBL) is pedagogical approach inspired by John Dewey, an American philosopher, psychologist, and educational reformer, who asserted the imperative of hands-on experience or learning by doing (Lam, 2008) and by forcing students to solve complex and open ended problems, which can significantly improve the integration of knowledge (Lowenthal, 2006). According to Prince and Felder (2006: 14) PjBL is defined as:

> *Project-based learning begins with an assignment to carry out one or more tasks that lead to the production of a final product—a design, a model, a device or a computer simulation. The culmination of the project is normally a written and/or oral report summarizing the procedure used to produce the product and presenting the outcome.*

PjBL is well-known among engineering education researchers. Much of the literature reported how they designed and implemented the model of PjBL into teaching and learning and eventually they evaluated and assessed the effectiveness of the model. Many authors stated that PjBL is effective to develop non-technical and technical skills among engineering graduates. The traditional method of teaching for engineering education is not effective anymore nowadays because the skills of the 21st century engineer cannot be developed through this method (Vanasupa et al, 2007). Gradually, this type of approach cannot be used anymore in engineering education as it has become obsolete. López (2007) had summarized the relationship between teaching strategies and educational objectives as shown in Table below.

From Table 1, project development covers all the educational objectives in order to develop the students' skills from both aspects. This project development can be achieved through the implementation of PjBL as a teaching strategy. Department of Civil Engineering, Universiti Malaya had carried out PjBL and they found that it is the best method to implement Outcome Based Education (OBE). Engineering Surveying Camp was integrated in the first year Civil Engineering course that had three main course outcomes: i) the foundation of knowledge regarding engineering design; ii) technical knowledge regarding engineering surveying; iii) non-technical or generic skills.

Table 1: Relationships between educational objectives and strategies.

Objectives	Master lectures	Project develop-ment	Project public presentation	Compre-hensive exam	Lab
1-10. Technical	X	X		X	X
11. Critical thinking, analysis and comprehension	X	X	X	X	X
12. Teamwork		X	X		X
13 Oral and written communication		X	X	X	
14. Planning of work and study		X	X	X	X
15. Information management		X		X	
16. Decision making		X	X		
17. Gathering and integration of information		X		X	
18. Solidarity, justice and progress X	X	X			X
19. Life-long learning	X	X	X		X
20. Sensitivity for the environment	X	X			X

The course outcomes were successfully achieved as students were satisfied with all the procedures and teaching methods (Roslan and Mokhtar Azizi, 2009). The Mechanical Engineering Department of Politeknik Kota Bharu also utilizes the concept of PjBL in their compulsory subject, which is project management in order to produce better engineering graduates who meet the expectations of the industries. Findings from the interviews of the students reported that this teaching method was fun as they found it made it easier for them to understand and improve their self motivation to proceed with their learning process. Furthermore, critical thinking, problem solving, and team working skills were also improved as well as their technical skills and knowledge (Md. Baharuddin et al., 2009). According to Savage, Chen and Vanasupa (2007), they integrated PjBL throughout the four year undergraduates engineering curriculum at Cal Poly State University. PjBL had showed impressive results that enabled the students to learn both the basic principles of science and cultivate the understanding of how they can be applied to solve design problems in applied engineering. As for students,

they really believed that this method of learning was better than the other method and they strongly felt that the projects gave them the opportunity to work as real engineers by applying all principles of science, mathematics and engineering to problems.

Walsh, Crockett and Zahed (2008) in their research stated that California Polytechnics State University has established project-centered collaborations with external bodies by developing Project Based Learning Institute (PBLI) as they try to provide and use multidisciplinary and learning by doing approach. The university-industries relationships are a gateway or channel for industries to become involved in the development process of engineering graduates' skills. They provide a number of projects to PBLI that will be given to senior students as their projects. Such approach is really advantageous to the students as they are exposed to the real world problems. Furthermore, benefits are two-sided because not only for university, but industries as well because they can use this relationship as a platform to recruit excellent graduates. The industries do not need to spend more money and time to retrain their fresh engineers.

COMPARISON PBL AND PjBL

Hong (2007) listed the differences between PBL and PjBL as mentioned below:

Table 2: Differences between PjBL and PBL.

Area	PjBL	PBL
Basic operational structure	Emphasizes on the development of students' skill to design and carry out project.	Emphasizes on the development of students' skills to design question.
Practice procedures	i) Recognize the final project ii) Identify who will be the target consumer iii) Find out the implication of the project iv) Design the project v) Create a milestone or Gantt chart for the project vi) Start working on the project vii) Solve any upcoming problems or conflicts viii) Finish the project	i) Students start to wondering and questioning as they face the problems ii) Students further study on the problems iii) Emergence of extra questions iv) Specify the scope of knowledge v) Suggest a plan to get additional information vi) Carry out essential researches vii) Share the new knowledge viii) Make the conclusions

In the real world, engineers will be working on the projects and must ensure that every project meets the customers' specifications and expectations. From the table, PjBL approach seems the more suitable for engineering education because it

provides the best practice for students that mirrors the task of an engineer in the workforce. This statement was reinforced by Mills (2003: 13) in her research that stated:

> *It therefore seems that project-based learning is likely to be more readily adopted and adapted by university engineering programs than problem-based learning.*

Lowenthal (2006: 1) in his research stated that:

> *Project-Based Learning incorporates methods from problem-based learning, cooperative learning, active learning and project management theory.*

From the statement, it can be asserted that PBL is the subset of PjBL. If PjBL is implemented, PBL will be indirectly implemented as well. In addition to that, PjBL covers a wide scope of model of instructions that makes it the best method for engineering undergraduates. As for PjBL, it is likely to be correlated with engineering and science field, whereas PBL is also implemented in those fields, but it is originated from medical and other professional preparatory training (Ryan, 1996). Furthermore, PjBL emphasizes that students come out with an end product – something that can be seen instead of PBL that comes out with something abstract only. PBL has been readily adopted in medical education and probably because it "seems to mirror the professional behaviour of a physician more closely than the professional behaviour of an engineer" (p. 352).Clearer distinction between these two can be further made as stated in Table 3 below.

Notwithstanding, they share a lot of characteristics other than student-centered. The purpose of both methods is to connect the students with the real world tasks in order to improve the learning by working on open ended problems or projects. The role of teachers is never the same since they act as tutor, coach or facilitator (Hong, 2007). Teachers just guide them in order to make sure they are on right path and the teachers do not teach them in detail on how to do things as students must work in a group to complete the task given to them. Both methods provide the students with an in-depth understanding of a topic (Bell, 2010), connect the students to higher levels of thinking (Savery, 2006), provide students with auxiliary, flexible and stimulating environment (Maier, 2008) and based on constructivist learning theory (Donnelly and Fitzmaurice, 2005).

As students work on a project, team work skills will be developed because everything will be discussed and negotiated in groups. Indirectly, their verbal communication skills are also improved since they need to communicate with each other and make a final presentation. At the same time, their writing skills are also improved as they put some effort in doing report writing and their progress each week (Natasha, 2007).

Table 3: PjBL and PBL differences from various areas.

Area	PjBL	PBL
Objectives	To develop and improve technical and non-technical skills and provide real engineering practice for students	To enhance students' non-technical skills
End product	End products will drive the students to shape and describe the whole production, planning and evaluation process. E.g.: Usage of CAD in engineering project that needs a lot of effort and comprehensive planning	End products are much simpler E.g.: Group's report on the research findings
Knowledge	More directed to application of knowledge	More directed to acquisition of knowledge
Learning process	Learning process focuses on the production of model	Primary focus of the learning process is given to research and inquiry
Problems	An amount of problems will appear as students implicitly assume on the projects that problem solving skills are needed to solve them	Students start with clearly described problems and a set of solution or conclusions and direct response is needed.
Evaluation	Success of the PjBL is evaluated through skills obtained during the process of production of the model.	Success of PBL is evaluated through the how effective the solution is.
Implementation	Often related to engineering education and science instruction. Involves a lot of equipments, software and laboratories to produce a product.	Widely used in medical education and other professional preparation practices. There is a little or none equipment is used in the process of problem solving.
Time and resources	Project work is very time-consuming and a lot of time is needed to find the resources and they are limited. Student must know how to manage time and resources properly in order to finish the project before the deadline	Not very time consuming and resources are unlimited and easily obtained

Bell (2010) further added that students will learn accountability as they know that they must complete the task given to each member of the team. Students also learn how to monitor and evaluate themselves and team members. In the Malaysian scenario, Universiti Teknologi Malaysia (UTM) that implements PBL (Khairiyah, Mimi and Azila, 2004) and Universiti Malaya (UM) which implements PjBL (Roslan et al., 2009) have been compared from a few aspects.

Table 4: Comparison between Universiti Teknologi Malaysia (PBL) and Universiti Malaya (PjBL) model.

Area	Universiti Teknologi Malaysia (PBL)	Universiti Malaya (PjBL)
Problem	Students work on case study and learning issues	Real project where students need to make engineering surveying work on a piece of land
End product	Come out with a solution by brainstorming and present it to the class	Produce a survey plan that will be used by the owner to develop the land
Process	Can be divided into six main stages: i) Meet the problem ii) Problem identification and analysis iii) Synthesis and application iv) Reviewing step (ii) v) Solution presentation and reflections vi) Closure	Project management process

UM PjBL model provides experience that is closer to real engineering work and practice in the workplace. The students are working on a real project that they need to work in as a team for each process and planning. Project management skills are very important so that they can complete the project before the deadline as they need to plan and conduct the project by themselves without any structured steps. On the other hand, UTM PBL model uses case study that seems much simpler than project work since they only come out with ideas and solutions. Structured steps or stages are also provided for the students to solve the problems. Kolmos (2009) had conducted a study to compare the model of PBL that is implemented at Maastricht University and PjBL that is implemented at Aalborg University. He stated that the PjBL that is implemented at Aalborg is more student-driven and has more open ended projects, while Maastricht model is more teacher centered. The table below shows the comparison between both models.

Maastricht PBL model seems more structured because students need to follow all the seven steps in order to solve a problem and student centered learning is not fully emphasized.

Table 5: Comparison between Maastricht (PBL) and Aalborg (PjBL) model (Adapted from Kolmos, 2009)

Area	Maastricht (PBL)	Aalborg (PjBL)
Problem	Teachers define and prepare the problems	Students or facilitator defines the problem
Process	Using seven steps procedure: i) Clarifying problem ii) Defining problem iii) Brainstorming iv) Reviewing steps (i) and (ii) v) Formulating learning objectives vi) Self study vii) Sharing and reporting the results of self study	Project management
Team aspect	Students discuss the solution in group.	Students discuss and write in group. Students come out with an end product.
Assessment	Individual assessment	Individual and group assessment

CONCLUSION

Problem-Based Learning (PBL) and Project-Based Learning (PjBL) are two different approaches that people mistakenly assume both are the same although they have a lot of similarities. PBL approach is driven by the problem that is encountered by the students and focuses on research and inquiry, whereas the PjBL approach is driven by the end product that they want to produce and the main focus is given to the whole process of production. PBL begins with a problem and that problems become the main focus in PBL from which every progress, plan and work done by the students in PBL is directed towards solving the problems. On the other hand, PjBL begins with an assignment to carry out one or more tasks that lead to the production of a final product. Comparison made between PBL and PjBL proves that PjBL is more suitable for engineering education. The PBL approach, which was developed for medical students and intern practice, is less appropriate for engineering education. PBL lacks a few characteristics compared to PjBL which emphasizes the development of engineering skills by providing real life engineering practice. Furthermore, the PBL approach is closer to physician practice compared to PjBL. Thus, engineering students who undergo the PjBL approach will have a clear picture of what an engineer does in the workforce and directly motivates them to learn. It can be concluded that PjBL is the best method to teach and train engineering students to develop and enhance 21st century skills that are required by today's industries.

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