Problem Based Learning in Engineering Education: A Viable Alternative for Shaping Graduates for the 21st Century?

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Abstract - Engineering educators are faced with demands from various sectors to produce graduates who can be effective in today's borderless k-economy. To accommodate these demands and adapt to changes in the 21st century, Problem Based Learning (PBL) is proposed as an alternative to traditional lectures in moulding engineering graduates to acquire the desired attributes.

Although PBL has received a lot of attention, particularly in medicine, its implementation in engineering is not as encouraging. Engineering educators are sceptical that PBL is practical and applicable for engineering classrooms, given the high student to lecturer ratio, and the large body of knowledge that must be covered. Most importantly, can PBL really enhance learning and help students acquire the necessary generic skills?

To investigate if PBL is a viable option for engineering education, a qualitative evaluation of outcomes in several undergraduate engineering classes, conducted using the PBL concept, was performed. The result of the study indicated that PBL can be adapted for engineering classrooms and induced the desired outcomes on the students.

This paper discusses PBL, its benefits and potential in engineering education. However there are challenges faced by engineering educators in making the quantum leap from lecture-based classes to PBL.

Keywords: Problem-Based Learning; Engineering education

1. Introduction

The world we live in today is very different than in the past. The way things are done and work is performed is far removed in today's shrinking, borderless, knowledge-based economy compared to just a decade ago. There is rapid advancement and progress in knowledge and technology; the life span of technology is also short. The explosion in communication and computing technology results in an avalanche of available information, regardless of their authenticity.

Keeping this scenario in mind, engineering educators are pressed to produce graduates who are relevant in the 21st century. They need information mining, integrating and critical thinking skills to seek useful information. Graduates today must be flexible, self-directed and life-long learners to avoid having obsolete technical skills. Complex, multi-disciplinary and multi-faceted problems in the world today also requires graduates to be effective communicators, team-players and leaders. These are among the necessary skills essential for survival in the 21st century. These skills are also among the 10 attributes of an engineering graduate listed by the Board of Engineers Malaysia.

With all the rapid change and progress in the world, little has changed in the way engineering graduates are taught. Technology may have changed the chalk and talk method to include overhead projectors or computer (power point) presentations; the delivery style, however, is still very much the same, if not worse. Dimmed lights during computer presentations makes it difficult for students to take notes and more convenient to doze off. Content delivery is still teacher-centred lectures, just like decades ago [1].

In Malaysia, students in general are highly examination orientated. In schools, they are drilled on the correct way of answering examination questions rather than developing true understanding. In universities, with a large amount of content and didactic lectures being the predominant mode of instruction, engineering students resort to rote learning to commit lecture notes to their short-term memories before a test so that it can be reproduced. Students also detest reading books and journals, preferring printed notes and handouts, which they religiously refer to as if there were no other sources of reference. For most, the retention of material is only until the final examinations. It is therefore not surprising that students can hardly recall the previous semester's material, much less in several semesters after they graduate.

Generic skills of engineering students left much to be desired. Their self-confidence, communication skill and critical thinking skill need to be developed. Students are often unsure of themselves and of the knowledge that they have, and rarely posses self-checking and correcting skills. Class participation is minimal; questions asked in class are normally met with a deafening silence. Team working and leadership skills are also low; most students would rather work alone, or just in their own group of friends. Although there are undoubtedly good students who excel, every semester, the same observations are made on the majority of the students. With the current state of affairs in Malaysian engineering education, is it any surprise that there have hardly been any top leaders of the nation from the engineering profession? There is a void in leadership, especially in technical areas. Engineering educators need to produce leaders, and not just backroom boys. Therefore, the teaching and learning technique of engineering students must be improved to develop crucial skills to face the challenges and nurture leaders who can spear-head the nation in the 21st century.

2. Problem-based Learning (PBL)

2.1 What is Problem-based Learning?

Problem-based learning (PBL) is a teaching and learning technique that can develop the desired essential skills in engineering graduates. In PBL, learning is initiated through a realistic problem that has engaged the learner to find a solution [2, 3]. Students collaborate in small teams to identify, find and construct knowledge on new concepts that they need to learn in order to solve the problem. Among the many benefits of PBL on students are [2]:

- Critical thinking, analysis and synthesis to identify and solve complex problems
- Information mining to find, evaluate and use suitable learning resources
- Cooperatively work in a team
- Effectively communicate in verbal and written form
- Self-confidence and self-worth
- Continual and independent learning

PBL is characterised by the following features [3,4]:

a. A realistic problem, which captures the students' interest, is the starting point of learning
b. The problem challenges students' existing knowledge, attitudes and competencies, leading them to identify new knowledge (or learning issues) needed, and shortcomings that need to be corrected.
c. The responsibility and direction of learning is assumed by the students; faculty members are only there to facilitate students' thinking, learning and group functioning to help them resolve the problem.
d. Information mining from various sources, and utilization of evaluation to analyse what is really useful.
e. The process of identifying learning issues and problem-solving is as important as acquiring new knowledge to arrive at the solution.
d. Students learn in cooperative teams, where they need to interact and communicate to share knowledge, discuss their understanding and debate conflicting opinions.
e. Synthesis of various knowledge and information to arrive at the solution.
f. Reflection of the students' learning experience.

2.2 The PBL Process

Figure 1 shows the complete cycle of a PBL process. This framework is modified from [4]. The whole process can be divided into 6 main stages.

Meet the problem. The students read the problem scenario, reflect and articulate probable issues individually. They are encouraged to do background reading on the possible learning issues.

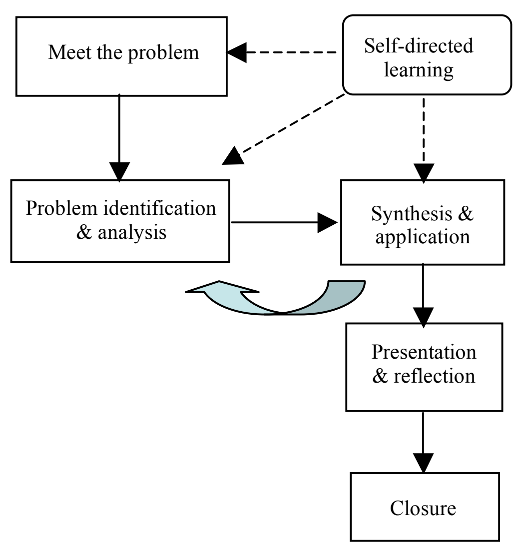

Figure 1. Framework of PBL process

Problem identification and analysis. The teams reach a consensus on the problem statement. They analyse the problem through brainstorming to generate ideas. At this stage, they also identify appropriate existing knowledge and the learning issues that must be tackled through self-directed learning. Facilitators guide the students so that they are on the right track checking and questioning the learning issues identified.

Synthesis and application. Students report their discovery from research and self-directed learning to their own teams. Information is shared and critically reviewed so that the relevant ones can be synthesized and applied to solve the problem. Facilitators at this stage must ensure that the coverage of the problem is sufficient, and probes students on accuracy and validity of the information obtained. This can be an iterative process, where students may need to re-evaluate the analysis of the problem, pursue further learning, reporting and peer teaching.

Solution presentation and reflection. The solution to the problem is presented to the class, followed by more probing questions by the facilitator to ensure deeper learning. Students are asked to reflect on the content as well as the process.

Closure. The facilitator integrates various knowledge learnt from solving the problem and encourages students to give their opinion on the value and usefulness for future learning and application to the work place. The facilitator also summarizes crucial principles and concepts, as well as eliminates any doubts that arise from the students.

2.3 Common Misconceptions

The following comments are among the common misconceptions of PBL.

I always give problems to students in class ... so I'm already practicing PBL. Giving problems from the end of a chapter to students after giving lectures is not PBL.

We use PBL in laboratories. Laboratory experiments conducted after learning the related subjects in classes are not PBL. If students have been taught in class, and the next semester are asked to conduct experiments from a problem statement, then that is project-based learning (also has the same acronym, PBL). Problem-based learning is concerned with the acquisition of knowledge, while project-based learning is concerned with the application of knowledge.

I give my students projects in class all the time – that's PBL, right? As in (b), this is project-based learning – PBL of the second kind – because students have been taught before the project is given.

PBL is learning without guidance. How can learning take place without a teacher? In PBL, students must be properly guided and monitored by facilitators. Good facilitation is essential for the success of PBL. In engineering subjects, facilitators must be content experts to properly guide students in the subject matter. The design of the problems for proper coverage is also essential for a successful PBL application, where students are "taught" through the problem.

PBL can only be applied for social sciences and humanities, and not engineering. There have been many applications of PBL in engineering throughout the world. The onus is really on the administrators and lecturers to try out PBL.

With PBL, the lecturer has less work / is not doing any work. There is actually more work for lecturers, especially in the initial implementations. New problems must be designed and vetted every semester. Lecturers must keep up to date to ensure that the problems reflect current practice and can properly facilitate and handle students' queries.

PBL is not suitable for students in Malaysia because of our reserved culture. Successful implementations in Malaysia have proved this to be wrong.

There is NO lectures at all in PBL. Mini lectures can be held if the topic is deemed to be important, or the problems given did not cover the topic.

3. Sample Outcome of PBL Implementations

There have been several PBL implementations in Universiti Teknologi Malaysia. The outcome of the results, and students' response of several implementations are discussed.

3.1 Results

Figure 2 shows the comparison of final results of two Material and Energy Balance classes for second year chemical engineering undergraduates taught by the same lecturer. The subject is notoriously known as a "killer" subject among students. It has a heavy syllabus, which covers important fundamental principles in chemical engineering. In the new curriculum starting next semester, the single subject has been split into two semesters to ease the burden on students.

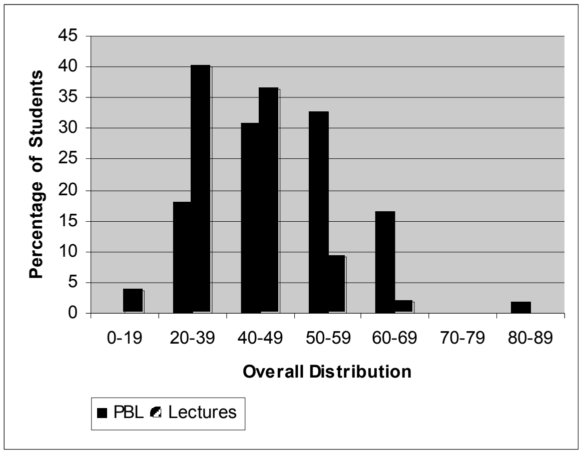

Figure 2. Final results for Material & Energy Balance Class.

Referring to Figure 2, the solid dark bars represent results from the 2004/05-1 semester where PBL was implemented fully. The other bars represent a previous semester typical result where pure lectures were given. As seen in the graph, the percentage of failures with PBL was much lower than lectures. Students performed better than those who attended lectures.

PBL had been implemented for two semesters in another "killer" subject, Process Control and Dynamics for fourth year chemical engineering undergraduates. In the first trial, PBL was implemented over a period of four weeks in two of the five classes offered. Students in the two sections who went through PBL performed much better on the question that covers the topics in the four weeks than students in other sections who had lectures. A more detailed description of the first implementation can be seen in [5]. In the second semester of implementation, the coverage using PBL was increased to seven weeks, while the rest was covered using cooperative learning. This time, PBL was implemented on all four classes offered – which means that the students did not have a choice. Although there were lots of room for improvement in the implementation, the results obtained by students were better compared to lecture-based classes. The percentage failure for the whole four classes was only 7%, compared to around 30% for a typical lecture-based class.

3.2 Students' Response

A questionnaire was given to students on whether PBL helped increase the four generic skills listed in Tables 1 and 2. Table 1 was the response of the two 4th year classes that went through 4 weeks of PBL in their Process Control subject in the first PBL implementation. Table 2 was the response of the second semester of PBL implementation for Process Control (Y4) and the 2nd year Material and Energy Balance class (Y2).

Table 1. Students in 4th year from 2 different sections

Generic Skills	Increased		The Same		Undecided	
	S1	S5	S5	S5	S1	S5
Problem-solving ability	76	96	15	4	9	0
Self-learning and motivation	87	96	7	4	6	0
Interaction and team-work skills	89	100	7	0	4	0
Self-confidence	70	84	18	8	12	8

Table 2. Students in 2nd year and 4th year

Generic Skills	Increased		The Same		Undecided	
	Y 2	Y 4	Y 2	Y 4	Y 2	Y 4
Problem-solving ability	100	89	0	7	0	4
Self-learning and motivation	89	94	11	4	0	2
Interaction and team-work skills	95	100	8	4	0	1
Self-confidence	95	88	5	10	0	2

When asked whether they like PBL, about 70% responded yes, slightly more than 20% undecided (ie mixed yes and no), and less than 10% a definite no. Nevertheless, more than 95% admitted that they have gained from PBL, especially on the generic skills, and were willing to take other classes that implements PBL in the future.

There are also numerous feedback obtained from students. Students who had experienced PBL after one semester appreciated PBL more once they realised the skills and positive attitude gained. One student in the first PBL implementation wrote:

"PBL opens my eyes on how university life should be. I was able to view the word "study" from a helicopter view. From what I see among my coursemates, PBL did change some of them from exam orientated to a learning style that is not only restricted to the syllabus. I'm able to think outside the box and think further, even though the changes are not drastic, it is a good thing for me."

Another wrote:

"PBL improved my generic skills. Now I feel more comfortable to work in a group and have confidence to solve problems. At least I won't feel scared when facing a problem that I have never seen before."

From the response obtained, PBL helped students to mature as learners, although they may first resist ("*Now I feel like a student in university, and not in school*"). They actually appreciate that they are given the chance to think and explore on their own, and not being spoon fed ("*PBL really works! No spoon-feeding 'coz we're grown-ups. This is the best and most enjoyable class!*").

Many were surprised that they can work well with others from different races and background *("... helps in knowing people of different races that I'd never got the chance to mingle with*.").

There were, of course, negative responses especially in the initial phases, though in the end there were much fewer. Among them:

> *"PBL is not suitable for Malaysian students because here we do not deal with anything practical, only theories."*

If this remark is true, it's time we change the perception on engineering education. Another wrote:

> *"PBL? WHAT ARE YOU TRYING TO DO? CHANGE OUR MENTALITY? WHY DON'T YOU CHANGE US FROM THE BEGINNING IN FIRST YEAR? INSTEAD OF IN FINAL YEAR?"*

There were in fact several who said that it's too late to introduce PBL in the fourth year class, while there are others who were thankful that they had a chance to experience PBL although it was almost "sunset" for them. Still, there are others who recommend that PBL should be used in the first year subjects, and even from secondary and primary school levels (*"If I'm the Minister of Education, I will enforce PBL even on primary and secondary school students!")*. Of course, there are those who just can't accept PBL:

> *"I hate PBL! I'm here to learn Process Control and not anything else!"*

4. Challenges in Making the Change

4.1 Lecturers

Changing from lectures to PBL is analogous to making a quantum leap in teaching. Lecturers are afraid of changing to PBL because they have never experienced it themselves. They have learnt through lectures, and lectures have been efficient in covering the syllabus – so why change? However, they need to understand that there is a need for change because the world today is far from what it was just a decade or two ago. Therefore, talks and training should be attended to learn more about PBL.

There is a paradigm shift for lecturers from being in control and the centre of learning in the class, to being a facilitator of learning. The students take charge of their learning, and thus take "control". Initially, there may be a sense of loss, of being unsatisfied because they are not able to speak and explain much as in lectures. However, they will soon see that students are also able to come up with excellent explanations, and that lecturers have a chance to impart their experience in the problem scenario, and while giving the closure.

There are concerns that PBL takes a lot of time, and there will not be enough time to cover the syllabus. As an initial trial, it is recommended that lecturers take a part of the syllabus (eg. two to four weeks) and give a suitable problem over the same duration [6]. This will provide experience before full implementation, if a total implementation is possible. If the syllabus is not practical for the duration of a semester, than it is advisable to reduce or split the class into two semesters.

Another main concern is the lack of experience in handling groups, for example how to eliminate "free-riders". To properly handle group dynamics, lecturers are highly encouraged to use cooperative learning techniques. For this reason, it may be easier to start with cooperative learning rather than jumping straight to PBL.

4.2 Administrators

Administrators can make or break PBL. Administrative support both at the university and faculty level is important in a properly-planned university-wide implementation [2].

At the university level, awareness, training and a support system must be made available. University administrators must also initially gently remind and prepare all faculties for PBL, followed by a framework for implementation on selected subjects after a reasonable amount of time.

To encourage lecturers to take-up PBL, incentives must also be given. It is high time that innovations and excellence in teaching are recognised and be properly rewarded as recommended by the Boyer Commission [7]. Grants and awards must also be made available for research and innovation in teaching.

Support from the faculty administrators is also essential. Requests for suitable subjects, classrooms, and time slots for PBL must be entertained. There will also be complaints from disgruntled students, especially in the initial stage, reaching the administrators. Although the dissatisfactions need to be addressed, an open discussion with all parties involved is preferred over relayed complaints. It is extremely disheartening and discouraging to have administrators convinced by half-truths, before looking at the other side of the coin.

Accrediting bodies must also reassess the regulations imposed on engineering programs. Currently, the chemical engineering program in UTM is recommended to enforce that the final examinations for all subjects be at least 50% of the total grade. This regulation is definitely unsuitable for PBL, which stresses equally on the process and the content. It is also unfair on the students who had worked very hard on the case studies, only to be meagrely rewarded. It is also crucial to change this regulation if we are serious about changing our education system from being too examination orientated.

4.3 Students

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 tutors may also face difficulty as they prepare to facilitate discussion, provide coaching, challenge student thinking and manage group work, especially if it is the first time that students face PBL.

Students facing PBL for the first time get a shock when they are handed back their responsibility for learning. A common grouse was how can they be asked to do something that they have not been taught. They lack familiarity with inquiry learning, often unclear about how they can relate what they are currently reading to what they already know. Those who persist on soon realise that it is possible, when they have an appropriate learning context, seek the necessary information, and see how things finally "come together". Many reported in their reflection that they find it very rewarding and felt their confidence grow when they are able to explain to others and contribute to solve the problem. As one student wrote:

> "*PBL is very challenging. It literally invokes the fighting spirit in you because it lets you drink in water when you're learning to swim*."

Resistance from students is to be expected, even though several hours of explanations on PBL have been given early in the semester. Motivation and counselling, even individually, must be given. This is because uncooperative individuals affect the success of PBL not only on themselves but also on their group members.

Students' complaints, nevertheless, can be very harsh that they sometimes made it seem as if the efforts were not worth it. Their complaints reach all the way to the administrators and the academic advisors. In another university, where the students' society is very strong, a contract lecturer had to abort PBL after being threatened that they will complain to the top. In a mid-semester anonymous evaluation in the fourth-year class, a student asserted that "*everyone hates PBL*", when less than 10% actually stated their dislike. Student-orientated lecturers who have always received praises from students will find these comments difficult to swallow. The lecturers, therefore, have to be as resilient and open-minded as they expect their students to be. The negative comments may be helpful for improvements, but they are not to be taken personally. There are many students who appreciate the effort. During the same evaluation exercise, lecturers in the fourth year class received many positive comments and encouragement, like the one shown here:

> *"Good work! Keep it up! It really shows that you guys are dedicated and concerned in ensuring that students understand and enjoy learning, not only process control, but for life in general. You are good role models to be emulated."*

5. Conclusion

Problem-based learning is a viable alternative in preparing engineering graduates for challenges in the 21st century. The qualitative study on the implementation in Universiti Teknologi Malaysia proves that PBL is able to not only impart content knowledge, but also generic skills essential for today's economy. More importantly, students who embraced PBL flourish into matured learners and thinkers to become better citizens who can contribute to the nation's growth.

References

[1] Rugarcia, A., Felder, R. M., Woods, D. R., and Stice, J. M.,"The Future of Engineering Education: I. A Vision for a New Century", Chemical Engineering Education, 34(1), 16-25, 2000.

[2] Duch, B. J., Groh, S. E. and Allen, D. E. *The Power of Problem-based Learning*, Stylus Publishing, Virginia, USA, 2001.

[3] Boud, D. and Feletti G. *The Challenge of Problem-Based Learning*. New York: St. Martins' Press, 1997.

[4] Tan, O. S.(2003) *Problem-Based Learning Innovation: Using Problems to Power Learning in the 21st Century,* Thomson Learning, Singapore.

[5] Khairiyah MY, Mimi HH and Azila NMA, "A First Attempt at Problem Based Learning in Process Dynamics and Control Course for Chemical Engineering Undergraduates at Universiti Teknologi Malaysia", 5th Asia Pacific Conference on Problem-based Learning, Kuala Lumpur, Mar 2004.

[6] Woods, D. R., *Problem-based Learning: Helping Your Students Gain Most from PBL*, 3rd Edition, 1996.

[7] Boyer Commission on Educating Undergraduates in the Research University for the Carnegie Foundation for the Advancement of Teaching, *Reinventing Undergraduate Education: A Blueprint for America's Research Universities.* URL: http://notes.cc.sunysb.edu/Pres/boyer.nsf, 1998.