

How can engineering students' problem solving skills be improved?

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ABSTRACT: Problem-Based Learning (PBL) emphasises the learning process in which students actively engage in collecting information and working through a problem. However, many studies have indicated that not all students would benefit from the original form of PBL. This article presents a study wherein the PBL model is modified and developed into a form that is suitable to both deep and surface biased students with regards to skill development and learning. This study was the first of its kind to demonstrate the effectiveness of a hybrid PBL model on improving students' problem solving skills in a vocational engineering course.

INTRODUCTION

Society nowadays becomes complicated and dynamic. To suit society's needs, it is undesirable for universities and colleges to produce graduates who can only work within the restricted framework of solving textbook problems or just reproduce existing designs. People are expected to adjust their performance to accommodate variations in the demands of everyday tasks [1]. Thus, universities or colleges should also modify their education system to match the requirements of industry and commerce. Curriculum should be reformed to create classrooms in which students are challenged to think profoundly about subjects by discovering, understanding, analysing and applying knowledge in new situations [2].

In line with curriculum reform, graduates need to acquire transferable, problem solving skills to enable them to gain employment in an unpredictable environment [3]. Some students can obtain these skills easily but other students fail to do so in their college life. Some students can learn basic concepts, master knowledge, use the content learned constructively and then apply it to daily life. Other students think that they already have grasped the concept of a theorem taught in class but have trouble solving problems based on that theorem. Part of the reason for this difference is because students have different learning approaches [4]. Students with a surface biased approach have a tendency to assume a passive role and expect their instructors to show them how to solve problems. On the other hand, students with a deep biased approach learn with intrinsic interest in the task and the logical strategy that flows from that is to satisfy one's curiosity by finding out as much as one can by understanding it [5].

Conventional teaching emphasises that the teacher's role is the transmitter and student is the absorber of knowledge [6]. This teaching and learning approach has produced graduates who lack the transferable skills required by industry. As teachers and trainers, how can we help students learn correctly and obtain these skills? How are we going to engage all students in the deep learning process so that they can resolve problems themselves?

In fact, it is better to provide a learning environment that facilitates students' development of problem solving and cognitive skills, enhances students' acquisition of knowledge and encourages the retention and transfer of such skills, knowledge and abilities to other situations [2]. This study delimits the exploration and evaluation of Problem-Based Learning (PBL) as one form of learning environment and looks at its effects on student learning and problem solving.

PROBLEM-BASED LEARNING

Problem-Based Learning (PBL) is one of the methods to improve the quality of student learning [7]. PBL was found to maximise learning outcomes [8]. There were many studies on the effectiveness of PBL in increasing knowledge retention and fostering deep learning [9]. Barrows and Tamblyn advocate that this student-centred approach increases motivation because students are given chances to generate learning issues and thus take ownership of their learning [10]. Dolmans tested the effectiveness of PBL in three studies and found that students were assumed to be better able to learn and recall information [11]. PBL can also enhance students' general problem solving skills. Students can better integrate basic science knowledge into the solutions of clinical problems by using PBL.

There were a number of successful examples of the use of PBL in engineering disciplines. PBL was found to be effective in a building systems course where learning was seen as a constructivist process [12]. The problem-based element was added to the course where students worked in groups to create new knowledge in the form of interactive multimedia presentations. A similar case was found at the Conventry Polytechnic: most students from an engineering degree course were found to take a surface approach to learning in their first year of study [13]. PBL was then introduced in their second year syllabus. At the end of the second year, the number of students adopting the surface approach declined significantly. Maskell and Grabau used the multidisciplinary cooperative PBL approach for embedded system design [14]. PBL was then proven to be ideal for engineering education as it encourages a multidisciplinary approach to problem solving, which is essential for modern engineering practice.

PBL was first introduced for use in medical faculties to solve some important problems of medical education, such as the difficulties encountered by students to practice the knowledge gained in a clinical setting and a lack of integration of the knowledge acquired in the different disciplines [10]. The original form of PBL is an instructional method that uses highly practical real world cases or problems as vehicles to acquire critical thinking and problem solving skills. New knowledge is acquired in the context of some related problems or situations. Students may choose a problem within a larger topic or theme and then design, develop and modify a solution mode or pathway to resolve the problem. With the guidance of the instructor, students actively engage in problems and build their own understanding by their own efforts.

This form of PBL applies to small class sizes and facilitates students to discuss the problem as a group, or to clarify terms and concepts not readily understood by making use of the group members' knowledge. Based upon common consensus, the group proceeds to generate hypotheses necessary to analyse the problem. They then begin to define *learning issues*, which are more or less what they do not know and need to find out in order to solve the problem. These learning issues serve as guides for studying the literature or searching for other sources. Learning resources are considered and here the instructor and students decide on where they can find the relevant information.

At the next session, students inform each other about their findings and teach the rest of the class about what they have learned about their assigned issues. Attempts are made to integrate the new information and to relate it to previous knowledge. If the learning process raises new questions or leaves some issues still poorly understood, these are also listed and the cycle is repeated until a satisfactory evaluation and clarification of the case can be made. This second meeting aims at checking whether a deeper understanding of the problem has been reached. In all of these processes, the instructor attempts not to inform but to guide, support and encourage the students' initiatives.

However, Woods mentions that there are possible disadvantages to PBL [15]. Students may be uncomfortable with PBL simply because they are so used to subject-based learning. The second one is that with PBL, students take longer to learn the same subject content (but can learn deeper and with more interest). Another disadvantage is that in tests that seem to check factual recall and factual information, PBL-taught students perform poorer. Also, the PBL approach assumes that students are good at problem solving. As students are familiar with subject-based learning, their problem solving skills may not be competent enough to achieve PBL.

HYBRID PROBLEM-BASED LEARNING

Many studies have indicated that not all students in classes may benefit from the original form of PBL [8][16]. Tang et al, in their study of PBL within the Hong Kong Polytechnic University, point out that consideration should be given to the actual teaching and learning context [16]. A direct importation of the typical model of PBL is inappropriate because every discipline has its own content knowledge and philosophy that would be achieved through a particular teaching approach. As a result, there is a growing need for teachers to develop a context-based PBL model to improve students' problem solving skills and to help them construct their knowledge.

In this study, the original PBL model was modified and developed into a form that was suitable to both deep and surface students in a vocational engineering class. Additional guides for students were provided in this hybrid model to improve the students' problem solving skills. The present model in this study was modified from a hybrid PBL model used in a case study from the Hong Kong Polytechnic University [16]. This hybrid PBL model started with a problem given to a group of students at the beginning of the term. A variety of teaching and learning modes were then used to augment the students' problem solving skills and acquire basic knowledge in order to solve the given problem.

DESIGN OF THE STUDY

Subjects

The subjects in the experimental class were first year engineering students (N=74) studying at the Hong Kong Institute of Vocational Education (Tsing Yi). Another 74 students in a control class were taught using a conventional teaching approach. As first year students were strongly influenced by their previous learning experience in secondary schools, they expected a didactic teaching approach from their lecturers and adopted a passive learning approach [16]. If the original form of PBL had been implemented, where there were no lectures but enough guidance, students would get lost in their learning and lose interest and motivation in studying [15].

Hybrid PBL Treatment

In a large class of engineering students, students freely formed groups. The members of each group (3-4) were the same throughout this period of study. The hybrid PBL model was applied to this class for 15 weeks. This PBL model started with a main problem that was given to a group of students at the beginning of the semester. This main problem was given to the experimental class at the beginning of this study. This problem was designed in such a way as to:

- Cover the topics written in the syllabus of this subject.
- Relate to the future career of the students as engineers.
- Enable students to appreciate the technique in the design and troubleshooting of circuits using different components.
- Develop problem-solving skills and stimulate critical thinking, which are required for engineering work.

A variety of teaching and learning modes were used, including lectures. The first lecture of the experimental class started with an introduction of the main problem. The background of the main problem was given to the students and the lecturer would answer questions from them. In the following series of extended lectures, supporting materials on these questions were presented to give students an idea about the type of foundational knowledge required. Students were given autonomy to decide on the relevant materials to support them to find the solution of the main problem.

Problems were given during lecture. These problems were similar in nature to the main problem but on a smaller scale. All problems were either given in the lecture or tutorial and would be finished within the class or the results presented in next session. They were designed in such a way as to enable students to appreciate the technique in the design of logic circuits and to develop problem solving skills to support the solving of the main problem and benefit their future career.

Further support was provided in the tutorial sessions. The aim of the tutorial was to develop students' skills to solve practical problems based on the topic that they had learned in the lecture. Practical problems that required students to apply the basic knowledge learned in the lecture were given at the beginning of the tutorial (N=20). Students within the same group discussed and helped each other to find information and solve these problems. Each group of students presented their results or ideas either at the end of the tutorial or in the next tutorial. During the presentation, classmates from other groups could have a chance to discuss or challenge the findings.

Each group of students had regular group discussions where they could define the learning issues and seek clarification from the lecturer if necessary. During this process, students focused on what they did not know and hence found out materials in order to solve the problem outside class time. The role of the lecturer was to facilitate the students' identification and location of the necessary resources.

At the end of this study, each group presented their findings to the whole class. The contents of the presentation included the idea formation, the way of handling the main problem, their findings and the final product design. The lecturer or other classmates could raise challenging questions to further probe the understanding of students in individual groups. The other students also learned from this presentation.

These teaching and learning modes were used to provide basic knowledge, improve students' problem-solving skills and assist in the handling of the problem. Students could acquire and construct knowledge in different teaching and learning modes. They could also obtain more practical skills and improve problem solving techniques.

Instruments

In order to assess students' approaches to learning, the Study Process Questionnaire (SPQ) was given to both experimental and control classes prior to the intervention [4].

A summative test was given to both experimental and control classes at the end of the study to assess the learning outcomes. This summative test consisted of two types of questions. The first task assessed the low-order skills whereas the second task tested the higher-order cognitive abilities. Based on the numerical results of this test, any change of memorisation skills or problem solving skills between these two classes could be found. Also, the learning outcomes of solving these two completely different types of questions between deep and surface students in this PBL programme could be studied.

At the end of the study, 16 students (eight surface and eight deep bias) were randomly selected for interviewing. The aim was to investigate, in an open-ended manner, how this hybrid PBL model might have affected their learning and their views towards this new teaching approach.

RESULTS AND DISCUSSION

Figure 1 shows the results from the low order skill question for students with different learning approaches in both experimental and control classes.

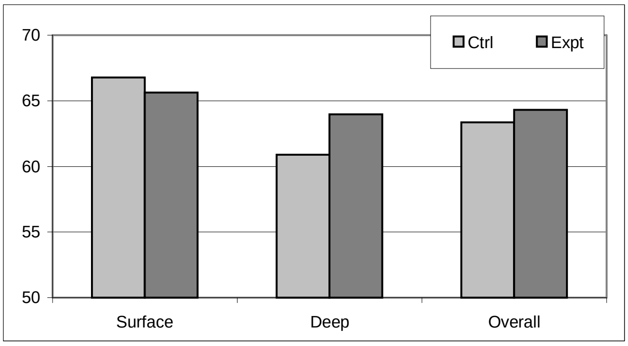

Figure 1: Results of the low order skill question.

The average score of low order skill question shows only slight differences between each student category in control and experimental class. Hence, this PBL treatment has no effect on student's low order problem solving skills.

However, differences existed between the scores of students of both learning approaches in the high order skill question (Figure 2). A two-way ANCOVA with approaches to learning and PBL treatment as independent variables, the high order skill scores as dependent and entrance physics scores as covariate, was performed. Only the PBL treatment, $F(1, 6179) = 8.416$, was significant at the 0.05 level. These findings conclude that the PBL treatment did improve high order problem solving skills of students of both learning approaches.

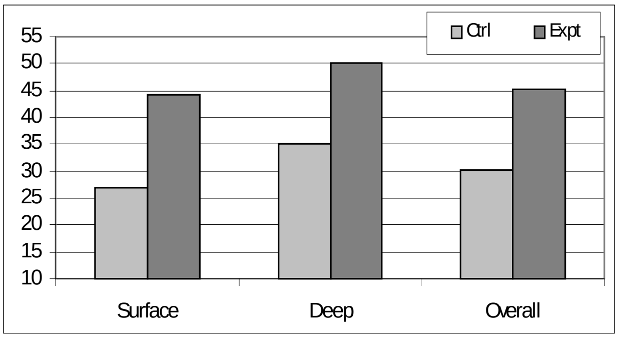

Figure 2: Results of the high order skill question.

Positive feedback was obtained from the student interviews. Most students enjoyed the chance to discuss together during the completion process of the main problem. Actually, students could teach each other and remember the discussion process for a longer period of time. This agreed with previous findings that the discussion part in the PBL model was an important process in facilitating students to think, generate learning issues and construct knowledge [10]. One student responded:

> *We discuss the problem together. Each member suggests a possible circuit and explains his/her circuit to the other members. Then we select the most possible circuit and test it. If the circuit does not work, we discuss together again. This discussion creates a strong impression in my mind.*

Students also reported positive changes in learning style after they had experienced this PBL model. For deep students, better time management, deeper thinking and different viewpoints were reported. For surface learners could benefit from this hybrid model, even though such learners were found to gain very little in previous PBL studies [8][16]. Although surface students were not so active in the discussion, they could learn difficult concepts through the discussion process. They also reflected that they had confidence to ask more questions after experiencing this teaching model, learned to transfer knowledge into practice and concentrated more during the lectures. These reasons show why surface learners also liked this hybrid model and had improved by the end of the study;

- *After using this model, I found that I have confidence to ask questions. This confidence is built up in the group discussion where you are encouraged to contribute rather than just sit and listen.*
- *By using this model, I learned to transfer the knowledge learned in class into practical work. In the past, I just learned the theory only without knowing how to apply it into practice.*

This teaching model created more interest for the students in learning and thinking. Students could learn deeply and remember the work done longer. Actually, the activities in this hybrid PBL model could solve some of the problems of the original form of PBL, such as student reliance on subject-based learning and assumptions of existing problem solving skills.

CONCLUSION

Both quantitative and qualitative results supported the previous findings that PBL could improve student problem solving skills [8]. This includes the acquisition of knowledge and the development of essential skills necessary in many careers [17]. In contrast to the results obtained by Lai and Chu, the present study also indicated that there was an increase in the problem solving skills of surface biased students [8]. This hybrid PBL model provides an environment for students to actively solve real life problems through the support of interactive lectures and tutorials. Students could express their different viewpoints through the discussion process and could learn different ideas from their peers to solve the same problem. Both deep and surface students were encouraged to think and benefit from this active learning process.

The present results suggest that students who are predisposed to both surface and deep approaches appear to show improvement under this hybrid PBL. It is important to further investigate the extent to which PBL actually promotes better problem solving abilities and would require longer exposure and more detailed online observations to confirm this. If this is true, then one of the main aims of teaching, to engage and develop higher-level cognitive processes in learners, would actually be encouraged by using PBL. As such, it is worthwhile placing more effort in this powerful teaching method.

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