DOI: 10.7763/IPEDR. 2014. V70. 14

Problem-based Learning: An Analysis of its Application to the Teaching of Programming

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Abstract. There are evidence that problem based learning (PBL), in comparison with other instructional methods, has value for enhancing the quality of students' learning and problem solving. PBL has a learning environment in which the problem drives learning, because it is posed in such a way that students realize they need to acquire new knowledge before the problem can be solved. This study examines the experience of an implementation of PBL approach to teaching of an undergraduate programming course at a higher educational institution in Brunei Darussalam. The study results further indicated the improvement among students' performance based upon problem-based methodology. A survey instrument was used to generate the quantitative data for subsequent evaluation and analysis using the SPSS statistical software. The finding from this study will contribute to our understanding of the difficulties in learning introductory programming and can provide educators with an alternative strategy for improving the teaching and learning of a programming language. The problem solving and soft skills gained through PBL as a teaching delivery method can also enhance students' employability once they graduate.

Keywords: Constructivism, Problem-based Learning, Collaborative Learning, Learning Programming, Brunei Darussalam.

1. Introduction

Teaching computer programming can be a challenge if it is faced with high failure rate and students' dissatisfaction. This is because programming can be a difficult undertaking for some. It is highly complex, with subtasks related to different knowledge domains and a variety of cognitive processes (Pea & Kurland 1984). Programming requires students not only to understand the relevant theory but also to be able to apply it to solve real problems.

Traditional methods of teaching computing courses have been largely teacher-centred. Teacher provides most of the information in front of the class while the students listen and absorb passively in their learning using mostly books as a source of learning and memorizing. Hence, students were not able to understand the applications of the lessons learnt as they were mainly memorizing the knowledge rather than searching and applying the knowledge. While this may have worked in the past, new realities have demanded a paradigm shift in the way learning should happen in a computing course.

A student-centered approach to teaching using PBL should be implemented to enable students to cope with this reality. PBL provides authentic opportunities to the learners to foster active learning, promote critical thinking, support knowledge construction and associates the learning to the real life problems.

PBL is now practically the standard approach in medical education in many countries across the world including Brunei Darussalam (Wood & Head, 2004). In some countries, PBL has also been used in other disciplines. But in Brunei, to the best of our knowledge, PBL has never been used in programming education at higher educational institutions. This pioneering study investigates whether the PBL approach improves learning of programming and strengthens students' analysis skills and problem-solving abilities. It describes the implementation of the PBL approach to the teaching of a computer programming course to a group of undergraduate students. A set of integrated real life problems was chosen as a stimulus for the students. Both

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a face-to-face learning environment and a group environment were set up to encourage self-learning and collaborative learning.

2. Definition of Problem-based Learning

The modern history of PBL begins in early 1970s at the medical school at McMaster University in Canada (Barrows &Tamblyn, 1980). Since its introduction, it has been used in various undergraduate programs around the world. In PBL, students must learn to apply knowledge not just acquire it. PBL is a student-centred instructional strategy that is used to promote active learning. PBL derives from the theory that learning is a process in which the learner actively constructs knowledge. Learning results from a learner's actions; instruction plays a role only to the extent that it enables and fosters constructive activities. Instead of the teacher simply providing lectures about the solution, the students are presented with or identify their own problem that drives their inquiry and learning process (Hmelo & Ferrari 1997; Delisle 1997).

The theory underlying PBL is constructivism. Constructivism is a cognitive approach of learning and stress on the importance of the learners' previous knowledge (www.funderstanding.com/constructivism.cfm). Constructivism designs the teaching process with an opposite thought, which is "Learning during the process of solving problems". Learning occurs when students are able to connect new information with knowledge and experiences they have already assimilated (Duffy and Jonassen, 1992). Teachers can design some meaningful problems according to teaching contents, and then let the students think and try to resolve them. During the process, teachers can provide some support and guidance and organise students to discuss and cooperate. Teachers' activities should not impede the independent thinking of students. During the process of solving the problems, students construct new knowledge from their experiences. When they assimilate, they incorporate the new experience into an already existing framework without changing that framework. Here students play an active role in the learning process. Such methods are conducive to cultivating students' creative thinking skills and problem-solving abilities. Brooks and Brooks, (1999) provided the following guiding principles of constructivism. Accordingly, they viewed learning as an active process and classified as: (1) learning as active process (mental or physical), 2) learning is a social activity, 3) learning is contextual, 4) learning needs knowledge and 5) learning takes time.

3. Literature Review

There is enough evidence in the literature to support the benefits of PBL (Swan, 2005). Since the mid-1960s, PBL has made a significant impact on medical education (Norman and Schmidt, 1992).The application of PBL in medical education focused on clinical training. Problem relevance was considered as the most important factor for increasing motivation and developing the skills of clinical reasoning (Barrows, 1986). For instance, in their study, Dorsch, *et al.* (1990) described a multidisciplinary team in a problem-based format taught a ten-week critical appraisal course, the course was well received. Student satisfaction with their learning environments has also been extensively researched with medical students (Davis, 1994), nursing students (Rideoutet *et al.*2002), physiotherapy students (Solomon and Finch, 1998), and occupational therapy students (Stem, 1995). The results indicate that PBL approach is viewed positively by learners, who describe it as enjoyable, interactive, relevant, practical and holistic.

The adoption of PBL in Information Systems (IS) helped develop the students' generic skills required of an IT professional, such as analytical, problem-solving, creative thinking, teamwork, technical, and communication skills (Yip, 2002; Qiu & Chen 2010; Hou, Yang & Liu 2010; Peng 2010; Huang *et al.* 2010). In a teaching experiment, PBL was deployed as an alternative instructional method in the domain of Information Science and its effects on improving students' key competencies were supported (Greening, Kay, Kingston and Crawford, 1996). Similarly, Yip (2001) pointed out that PBL can enhance competencies both in professional and Information Systems education. While the interventions of PBL in the domain of medical and IS education were different, PBL is much the same in nature. It is a type of apprenticeship for real-life problem solving, helping students acquire the knowledge and skills required in the workplace (Dunlap, 2005).

In the application of PBL in computer programming course in China, Peng (2010) concluded that "PBL does a good job" in strengthening students' analytical skills and problem solving abilities and cultivating self-learning abilities. However, in a similar application of PBL in programming teaching in Brazil, Ambrosio (2011) verified that PBL alone is not enough for some students. She argued that abstraction and command sequence abilities are also needed to succeed.

In Brunei, Wood (2006) studied the first use of a PBL approach to teach English for Academic Purposes (EAP). He concluded that PBL can be and has been applied successfully to the teaching of medical EAP at the Universiti of Brunei Darussalam. Looi (2013) made a first preliminary application of PBL in teaching programming and verified that PBL had helped in improving students' overall academic performance in programming.

4. Research Methodology

4.1. Course setting

The course under study is a full semester (18 weeks), 20 credit value, targeting at the first year undergraduate students enrolled on the four-year programme leading to a Bachelor of Science degree in Internet Computing at the Institut Teknologi Brunei in Brunei Darussalam. The course under study is known as "Programming Principles and Techniques". The course involves six hours of timetabled contact per week (2 classroom/theory hours, 2 tutorial hours and 2 practical lab hours) for a total workload of 20 credit values. This compulsory subject covers the basic programming principles and techniques for the Java programming language. This course aims to equip students with the necessary knowledge and ability to write their own very basic Java applications. There is no prerequisite for this subject and the assessment scheme adopted was 70% for the final exam and 30% for the laboratory work.

Over the past years, the teacher-centred approach based on lectures and some practical laboratory sessions were used in this course. High failure rate and students dissatisfaction have initiated our search for an alternative approach to improve learning.

4.2. Instrumentation

This research is a quantitative study. A survey instrument was used to generate the quantitative data for subsequent statistical analysis using SPSS for conducting descriptive as well as using paired samples t-test. The survey instrument aimed to evaluate the impact of the PBL activities conducted on their communication and problem solving skills, the impact of PBL on the process of acquiring knowledge through self-learning, and whether PBL encourages students to be self-motivated, curious and generate thought. The questionnaire consisted of 18 questions grouped into 6 categories as follows:

No	Category	No of Questions	Reference
1	Opportunities for collaborative learning	4	Qui & Chen (2010)
2	Ability to learn from others	3	Qui & Chen (2010)
3	Increase in motivation & interest	2	Barte & Yeap(2011)
4	Availability of peer support	2	Qui & Chen (2010)
5	Improvement in social skills	2	Barte & Yeap(2011)
6	Improvement in problem solving skills	4	Barte & Yeap(2011)
	Total	18	

The six categories were carefully selected to reflect the characteristics of PBL and the areas in which PBL has indicated benefits. To improve the reliability of the response, each category was carefully designed to consist of two to four questions. To measure the effect of PBL before and after its implementation, each question was divided into 2 parts. One part was for gathering responses before the implementation of PBL and one part for responses after the implementation. Students were asked to express their opinion on 1-5 Likert scale with 5 representing "strongly agree" and 1 representing "strongly disagree".

4.3. Group Formation

Group formation is a requirement for PBL implementation. A total of 43 students, enrolled for the course for the 2012-2013 academic year, were divided into eight groups of four or five. A group leader was carefully appointed for each group. Each group member was given different resources and assigned a different role. The roles were: the group leader, the Checker, the Recorder and the Sceptic. The leader had to subdivide the tasks, assign responsibilities, maintain the pace of the work and check the quality of the performance. He/she also had to produce a short report explaining how the work was divided and the criteria used to assign it to the different team members. This way each student could concentrate on a part of the material without worrying about having to understand the rest of the material. The Checker had to monitor not only the solution but also its understanding by all members. The Recorder had to check if there was consensus and had to write the final version. The Sceptic provided alternative suggestions, keeping the members from jumping to premature solutions (Felder & Brent 2001).

The assignment of different role and different resources to each member in a group aims at fostering interdependency necessary to carry out their problem solving work. Face-to-face interaction is rather important in this type of work. They have to rely on the others and create their own sense of responsibility to study his/her part of the topic that will later on help to compose the final task. As the final evaluation will be on the whole subject, there must be a constant feedback of information to update all the team members on the whole subject matter (Johnson *et al.* 1991). Along the way, students met with their teachers to be provided with the necessary details for the performance of the task. These meetings intended to guide the groups towards a solution by introducing them to further specific information they would need in order to reach a solution. At the same time, the meetings served as progress checks, as the teacher would met with each group leader.

4.4. Teaching Approach

The course was taught in early 2013 using the traditional teacher-centred method for the first half of the semester and the student-centred PBL method for the remaining half of the semester. During the second half of the semester, the instructor acted as a facilitator or guider. Organized in groups of four to five people, the students started working with very simple, clearly defined problems and gradually moved on to more complex ones. The early problems, here called tasks, were aimed at enabling students to gain some basic knowledge of programming fundamentals as well as to give them some time to get to know each other in their groups. Due to the academic calendar and attendance requirement of the university, there was no possibility of avoiding the traditional weekly timetable. The students therefore attended the formal lectures as a single group and worked in teams during the tutorial and practical hours

5. Evaluation

5.1. Reliability Analysis

Table 1: Quality Control Statistics

No	Constructs	No of Original items	No of Items Retained	Alpha value (.60 and above)	Variance explained <.50	CR
1	Collaborative Learning	4	4	0.78	.58	.57
2	Learning from Others	3	3	0.89	.62	.71
3	Motivation & Interest	2	2	0.94	.68	.66
4	Peer Support	2	2	0.87	.60	.83
5	Social Skills	2	2	0.65	.55	.73
6	Problem Solving Skills	4	4	0.85	.61	.72
	Total	18	18			

All Items in the questionnaire were assessed for reliability using Cronbach's alpha (1957) prior to questionnaire distribution. Table1 presents the first run of alphas for all the six constructs. All Cronbach's alphas exceeded the minimum requirement of 0.70, indicating that all six constructs have more than adequate reliability for the next stage of data analysis. Similarly, the composite reliability (CR) and variance explained is above the critical limit of (<.50), thus fulfilling Hair *et al.* (1998) criteria for sufficient validity.

5.2. Demographic Profile of Participants

Table 2 presents the demographic profile of the participants. Notice that 85% of the students are above 25 years of age. This is because participants are working adults and attended the classes part time in the evening. Nearly 80% of the students indicated that programming subject is not easy. However, when asked about the effect of PBL on their performance in the later part of the questionnaire, nearly 90% of the students agreed that PBL had benefited them in one way or another.

Table 2: Demographic Profile of Participants

Degree	Bachelor in Internet Computing	43%
	Bachelor in Business IT	57%
Age	>=25	15%
	>=30	33%
	>=35	15%
	>=40	22%
	>40	15%
Programming Task	Very Easy	4%
	Easy	17%
	Average	53%
	Hard	21%
	Very hard	5%
English & Maths	English O level	42%
Qualifications	Maths O Level	48%
	Maths A Level	10%

6. Results

A paired sample t-test was used to determine whether there is a significant difference between the average mean values of the same questionnaire response made under two conditions (i.e. pre-PBL and post PBL). Both measurements were made on each unit in a sample, and the test is based on the paired differences between these two values. The usual null hypothesis is that the difference in the mean values is zero. Table 3 shows the mean value of pre-PBL and post-PBL response, the t-statistics and the p-value for each of the item in the questionnaire. Note that the p-value is .00, which is less than a standard alpha of .05, indicating that there was a statistically significant difference in the pre-PBL and post-PBL teaching conditions. We would reject the null hypothesis that they are the same and accept the alternative. In other words, PBL had made a positive difference to the students in terms of opportunities for collaborative learning, ability to learn from others, motivation & interest, social skills development, availability of peer support and problem solving skills development.

In terms of ranking, the construct *peer support* is ranked top as it had the biggest difference in the mean value in its two items (rank 1 and 2). Students perceived peer support as the most important benefits from the PBL learning environment. This is followed by construct *collaborative learning* and construct *learning from others*.

Table 3: Statistical Result of Paired-Samples T-test

	Mean Now	Rank	Mean Before	Rank	Rank Differ	t-Stat	P-Value	Remark
Collaborative Learning								
I have more chances to work in a team	4.55	10	2.30	13	-3	13.79	0.00	Significant
I have more chances to meet my classmates to discuss the problem	4.50	14	2.18	14	0	14.38	0.00	Significant
I have more chances to ask my classmates to explain their ideas	4.68	5	2.23	12	-7	14.94	0.00	Significant
I can explain my ideas to members of my team	4.70	3	2.05	15	-12	12.37	0.00	Significant
Learning from others								
I have more chances to learn a lot from others	4.58	9	2.35	10	-1	11.07	0.00	Significant
I have more opportunity to ask others about programming	4.69	4	2.38	9	-5	12.31	0.00	Significant
I have more chances to meet my classmate to discuss	4.63	7	2.45	8	-1	11.71	0.00	Significant
Motivation & Interest								
I am more motivated in learning this subject	4.53	12	2.60	5	7	10.27	0.00	Significant
I am more interested in the subject	4.60	8	2.68	3	5	9.75	0.00	Significant
I am more enjoying with this subject	4.62	6	2.58	6	0	10.12	0.00	Significant
Peer Support								
I get more support & encouragement from my classmate to learn	4.75	1	2.73	2	-1	10.98	0.00	Significant
I get more encourage from classmates to keep learning	4.71	2	2.75	1	1	9.78	0.00	Significant
Social Skills								
I get to learn how to work in a team	4.63	7	2.65	4	3	11.89	0.00	Significant
I learn how to listen, speak, share ideas, understand each other	4.66	6	2.65	4	2	10.15	0.00	Significant
Problem solving skills								
I understand better what the problem is/what the question wants	4.52	13	2.50	7	6	11.64	0.00	Significant
I understand better the steps to solve the given problem	4.53	11	2.35	10	1	12.42	0.00	Significant
I know which Java topics I must use/learn to write the program	4.30	15	2.18	12	3	10.00	0.00	Significant
I know better how to completely write program to solve problem	4.18	16	2.20	11	5	11.38	0.00	Significant

7. Conclusion

The results of this study verified that PBL is very effective in improving students' overall academic performance in programming. Computer programming course is to train a deductive way of thinking and therefore it is quite practical and very suitable to the method of PBL. The implementation of PBL was only carried out in the second half of the semester but very encouraging results have already been noted. In a period of three months, the students were able to improve their self-learning and critical thinking skills in addition to problem solving skills and social skills.

To capitalize on the potential of PBL, we hope to further enhance its teaching and learning efforts within the Faculty. With the initial success of this introduction of PBL as a learning method in programming, efforts

should be done to implement it for all the remaining subjects. However, we will continue to study how PBL will be best implemented for subjects that are more theory-based rather than practical-based.

This study opens avenues for other researchers within our university to investigate more areas on PBL and its application to other disciplines like engineering and business management. It is recommended that it be replicated and extended to other levels and other fields of studies. In addition, a larger study with a larger sample should be conducted to give a better picture of the effectiveness of PBL in teaching and learning programming. Although PBL is a student-centred and problem-guided approach, the content and scenarios are still teacher-centred. The design of content and problems in accordance with the interest of students remain an issue worth investigating in the future.

Successful implementation of PBL will not come easily. It may cause further difficulties at personnel, academic and financial levels. Lecturers will require extensive training. Fundamental beliefs will be challenged. Building a comprehensive PBL community requires determination and commitment from all levels – students, faculty and management – to make it work.

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