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Problem-based learning: engaging students in acquisition of mathematical competency

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Abstract

Previous research had discovered that students are trained to develop critical thinking, are adaptable to change, able to work independently, demonstrate effective communication skills and become continual learners through problem-based learning (PBL). A quasi experimental study was conducted to investigate the effects of PBL on mathematics performance, measure of instructional efficiency and perceived advantages or disadvantages of the approach. The experimental group was exposed to the PBL instruction whereas the control group was taught conventionally. The results indicated that there was no significant difference in the mean scores of the overall mathematics performance between the PBL group and the control group. On the other hand, there was a significant difference in mean mental effort between the two groups when given mathematics problem to solve. Overall, the PBL instructional strategy has promising implications in teaching and learning specifically in enhancing learning, thinking and communication among learners.

Keywords: Problem-based learning; instructional efficiency; engagement in learning; communication skills; mathematics performance.

1. Introduction

A review of the education system in Malaysia had been planned to meet the demands and challenges of globalisation and the k-economy. A student-centered approach was proposed in the teaching and learning process at all levels (primary, secondary and tertiary). At the primary and secondary level, the mathematics curriculum emphasised on several important aspects in teaching and learning which includes communication in mathematics, problem solving in mathematics and application of technology (Sharifah, 2003). According to the K-Economy Master Plan 2002 the important aspects for the development of k-economy and participation in the wave of globalisation are '*literacy; secondary enrolment; tertiary enrolment; enrolment in science and technology-related subjects; science graduates; technical graduates; expenditure on education; thinking and innovation skills; a*

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learning culture; lifelong-learning facilities; English language skills; receptivity to change.' (Ministry of Finance, Malaysia, K-Economy Master Plan, 2002).

The challenge of globalisation today requires students to acquire problem solving and communication skills, creative and critical thinking skills and positive attitude and values besides good conceptual knowledge of mathematics. Alternative to student centred instructional strategies in teaching mathematics have been suggested for teaching mathematics effectively in Malaysian secondary schools. Many research investigating the effectiveness of mathematics teaching strategies were conducted over the years. Among the strategies explored were cooperative learning (Effandi & Zanaton, 2007) and constructivism (Ng, Teoh & Tan, 2007). Problem Based Learning (PBL) is an engaging instructional strategy in which students are given 'triggers' or realistic, simulated real life problems that are ill structured, vague or ambiguous before they experience any training in a specific content area (Bridges & Hallinger, 1992). It was popularised by Barrows and Tamblyn (1980) following their research into the reasoning abilities of medical students at McMaster Medical School in Canada.

PBL in secondary mathematics education became popular in 1990 in the USA and was adopted by the Illinois Mathematics and Science Academy (IMSA) as its learning programmes and curricula (Savin-Baden and Major, 2004). In PBL the problem becomes the instrument for learning. Students are highly motivated to learn as the focus is no longer for the sake of school but they face real life problems and the learning is inevitable when solving these problems (Culver, 2000; Kain, 2003).Students taught in traditional mathematics education environments are preoccupied by exercises, rules, and equations that need to be learned, but are of limited use in unfamiliar situations such as solving real-life mathematics projects. In contrast to conventional mathematics classroom environments, a PBL environment provides students with opportunities to develop their abilities to adapt and change methods to fit new situations. Further, students in PBL environments typically have greater opportunity to learn mathematical processes associated with communication, representation, modelling, and reasoning (Smith, 1998; Erickson, 1999; Lubienski, 1999).

In general the purpose of this study was to investigate the effects of a PBL approach and conventional teaching (CT) approach in teaching mathematics. Two case study was conducted, one with secondary students and the other with senior high school students. Both the cognitive and affective attributes were examined. The cognitive attributes studied were mathematics performance, mental effort, and number of errors. The affective attributes such as teamwork, interest in mathematics, perceived usefulness of the PBL learning experience, mathematical communication and level of learning engagement during the PBL approach.

2. Methodology

This study adopts the quasi-experimental design which is deemed appropriate in its aim to investigate differential effects of PBL and the conventional teaching. A post-test control design was conducted over six week of implementation of PBL strategy for the treatment group and conventional teaching for the control group. Problem Based Learning (PBL) is a learning experience in which students are given problems before they experience any instruction in a particular focus area (Bridges & Hallinger, 1997; Mergendoller, Maxwell, & Bellisimo, 2006).

2.1 Problem-based learning versus conventional learning

In this study, PBL students were first given a problem before they were taught the statistical concept as stated in the learning outcome. They solved the problem based on notes which the teacher has prepared and also the explanations and examples given in their text books. The students then presented their solution as a group. The teacher went through the lesson again as reinforcement of the concept learnt. Conventional teaching refers to a teacher – centered teaching strategy in which the teacher introduces the topic or concept to be learnt, demonstrate using worked examples on the black board and later ask students to 'practice' in applying the principles and rules learnt by answering similar questions as shown in the worked example. The instruction given here is non-interactive and most of the time communication is one-way.

2.2. Measures of the study

Variables examined in this study are operationalized as below:

2.2.1 Mathematics Performance

Mathematics performance is the product of learning process. It is measured by tests or examinations. Scores, given through methods of calculations and correct answers represents performance shown in percentage. Mathematics performance in this study is based on scores obtained through a posttest given by the teacher after learning sessions for both PBL and CT classroom.

2.2.2 Mental Effort

Mental effort refers to the total amount of controlled cognitive processing in which a subject is engaged (Paas & Van Merriënboer, 1993). Mental effort is measured by a nine-point symmetrical category scale where the perceived mental effort is translated into a numerical value. Mental effort indicated the perceived amount of mental effort a student expended when solving mathematics problems given in the learning assessments during the acquisition phase and the posttest. This is indicated by circled responses to the nine point symmetrical scale shown by students on the Paas Mental Effort Rating Scale (PMERS) given at the end of each question on acquisition as well as test phase.

2.2.3 Efficiency index

This is a term which shows the relationship between learning and test (mental) effort and performance. In the study by Paas and Tuovinen (2004), mental effort (E) was measured on a scale of 1 (very, very, low mental effort) to 9 (very, very, high mental effort) whereas performance (P) was measured as the percentage of correct answers. The relative condition efficiency (E) is then calculated as

$$E = \frac{P - E_L - E_T}{\sqrt{3}}$$

Where E_L is the learning effort and E_T, the test effort (Paas & Tuovinen, 2004).

2.2.4 Affective attributes

These consist of measurement using Likert-scale items or rubric scoring. Perception of group work was measured based on a five-point Likert scale; 5 for “strongly agree’, 4 for “agree”, 3 for “less agree”, 2 for “disagree” and 1 for “strongly disagree”. Teamwork refers to the extent of students’ ability to work with each other, their attitude towards the task or other group members’ work, their quality of and pride in accomplishing their task. A score of 4 was given for the most acceptable trait and 1 with the least. Assessment was done by the researcher (instructor) based on the rubric throughout the lesson.

3. Results of Study One

Findings tabulated in Table 1 indicated that the mean overall performance score for the PBL group (67.4) was higher than the CT group (60.6). Detailed analysis also indicated that the PBL group seemed to perform better in the overall mathematics performance than the CT group. More students seemed to score grades A and B in the PBL group (62.3%) as compared to the CT group (45.9). However, analysis of covariance conducted indicated that the mean difference was not statistically significant, $F(1, 50) = 1.46$, $p > .05$. The results are shown in Table 1 and 2.

Table 1. Comparison of tested variables between the PBL and the CT group

Variables	Group	n	Mean	SD	Test	df	Sig (2 tailed)
Mathematics performance	PBL Group	29	67.4	19.75	F = 1.46	1,50	0.230
	CT Group	24	60.6	17.9			
No of errors	PBL Group	29	3.93	2.28	t = -1.04	51	0.303
	CT Group	24	4.56	2.04			
Mental effort	PBL Group	29	5.02	1.60	t = 2.70	51	0.009

	CT Group	24	3.90	1.38			
Efficiency index	PBL Group	29	-0.26	1.26	t = -1.70	51	0.095
	CT Group	24	0.32	1.22			

It maybe concluded that while the PBL group seemed to perform better in the overall mathematics performance than the CT group the difference was not significant. Information based on the eta squared value showed that the effect size of PBL on overall mathematics performance was also small (0.03) based on Cohen (1988).

Table 2. Analysis of covariance between the PBL and the CT group – mathematics performance

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	4880.388[b]	2	2440.19	8.71	0.001	0.26
Intercept	6022.55	1	6022.55	21.49	0.000	0.30
Pre PMR Scores	4273.88	1	4273.88	15.25	0.000	0.23
Group	409.76	1	409.76	1.46	0.23	0.03
Error	14012.78	50	280.26			
Total	238034.00	53				
Corrected Total	18893.17	52				

The comparison for mean mental effort per test problem between the PBL group and the CT group are shown descriptively in Table 1. Based on the PMERS a scale of 5 and below is considered as low mental effort and a scale of more than 5 as high mental effort. It was found that the CT group expended less mental effort during the acquisition phase compared to the PBL group. Only 4.2% of the students in the CT group recorded a high mental effort expended during the acquisition phase as compared to 17.2% in the PBL group. Comparison of the means mental load per test problem for the PBL group and the CT group showed there was a significance difference between the PBL group (M=5.02, SD=1.60), and the CT group (M=3.90, SD=1.38; t (51) =2.70, $p < .05$). The magnitude of the differences in the means was moderate with an eta squared = 0.13.

The mean relative condition efficiency index for the PBL group (- 0.26) differed from the CT group (0.32). Comparison of the mean efficiency index showed that there was no significant difference (t (51) =-1.70, $p < .05$) between the PBL group and the CT group. It maybe concluded that the PBL instructional strategy was just as efficient as the CT instructional strategy.

Total mean score for mathematical communication for the PBL group (8.00) were higher than the CT group (7.21). The PBL group also obtained a higher total mean score for teamwork (13.24) as compared to the CT group (12.46). They also obtained higher scores for working with others, attitude in group, keep focus on the task and proud with their work. In conclusion, the PBL group seemed to display better mathematical communication skills and showed stronger teamwork as compared to the control group.

Table 3. Means and standard deviations on mathematical communication and teamwork based on rubric

Mathematical Communication	**Means**		**Standard Deviations**	
	PBL	**CT**	**PBL**	**CT**
1 Mathematical language	2.90	2.58	0.41	0.83
2 Representation (tables and graphs)	2.62	2.46	0.56	0.83
3 Explanation	2.48	2.17	0.57	0.76
Total	8.00	7.21	1.55	2.42
Teamwork				
1 Working with others	2.66	2.50	0.55	0.83
2 Attitude in group	2.62	2.50	0.56	0.83
3 Focus on the task	2.62	2.50	0.56	0.83
4 Quality of work	2.59	2.67	0.73	1.01
5 Pride in work	2.76	2.29	0.91	1.00
Total	13.24	12.46	3.32	4.51

4. Results of Study Two

The aim of this study is to determine the effect of problem based learning approach to enhance student engagement and enrich the student learning experience. In this case study, a group of 24 Foundation Year students was randomly selected to introduce with Problem Based Learning (PBL) approach. This research was conducted on Calculus course while implementing the topic of derivative. The student engagement rubric and a set of open-ended questions were used.

Based on the students' responses, we found that more than half of the students (58%) like to learn in groups and 40% of them preferred to learn in pairs. These responses indicated that students preferred to work in teams rather than individual (25%). In term of their study approach, most students prefer case study approach (75%) and project approach (25%). However, half of this group preferred the conventional lecture-centred. During the learning process, nearly half of students (48%) prefer to learn through exchanging of ideas with others. Benefits of this approach as perceived by the students included the ability to discuss and correct their misunderstandings and strengthen development of transfer skills. Students stated that they felt more confident and independent and were therefore more willing to contribute to discussion. However, students agreed that PBL approach requires them to do a lot of self study and do a lot of research (84%).

Students were posed this question "What is your comment about this PBL approach?". Based on the students responses, seven positive themes emerged namely, fun working in groups, learn to locating own information for understanding of concept, able to apply interesting/relevant calculus concepts, accepting different perspectives within group, a stimulating experience, opportunity to learn in flexible time and, able to learn in order to learn new concepts. Clearly students in this approach enjoyed working in groups and recognize the various learning experience exposed during PBL.

On level of engagement in learning, eleven items using rubric scoring was utilized. For each of the items, a score of 3 was awarded indicating exemplary performance, a score of 2 for proficient performance and 1 point for partially proficient performance. Based on the rubric assessment 25% of the respondents had shown exemplary performance, 58.3% as proficient performance and 16.7% as partially proficient. Detailed distribution of each engagement categories are as in Table 4. The mean average rubric engagement score was 2.08, which indicated that the PBL group had benefited from the learning experiences with a proficient level.

Table 4. Learning engagement items

No	Item	Engagement Categories		
		Exemplary	Proficient	Partially Proficient
1.	Consistently stays focused on the task given and is self directed.	29.2%	37.5%	33.3%
2.	Contributes as team member and encourages and supports the efforts of others in the group.	16.7%	50.0%	33.3%
3.	Follows through on assigned tasks independently and responsibly.	16.7%	58.3%	25.0%
4.	Asks insightful and challenging questions to help understanding and learning.	12.5%	54.2%	33.3%
5.	Demonstrates poise and confidence when answering questions.	25.0%	45.8%	29.2%
6.	Active learner showing interest in learning.	16.7%	58.3%	25.0%
7.	Gathers and shares useful ideas when participating in the group discussion.	20.8%	45.8%	33.3%
8.	Makes necessary steps to accomplish a common goal and help keep the group working well together.	33.3%	33.3%	33.3%
9.	Has a positive attitude about the task(s) and the work of others.	20.8%	50.0%	29.2%
10.	Performed duties assigned as team member and contributes knowledge, opinions and skills to the team.	20.8%	50.0%	29.2%
11.	Acceptance and tolerance behaviour during learning.	16.7%	54.2%	29.2%

[Exemplary - 3 point ,Proficient - 2 point, Proficient Partially - 1 point]

This study strived to ascertain the effects of PBL on mathematics performance and instructional efficiency. It also compared the affective products of learning between PBL and the conventional teaching strategy. The numerous positive effects of PBL such as becoming better problem solvers, demonstrating effective verbal and written communication skills and are able to work collaboratively were also shown in this study. However, minimal differential effect on mathematics performance and instructional efficiency was obtained between the PBL and CT group. Hence, this indicated that the efficacy of PBL has yet to be explored in enhancing mathematical performance and to develop problem solving skills, critical thinking and communication skills among learners. Central to the effectiveness of PBL is the ability of students to work together to solve problems. The relevance of applying mathematical concepts to an authentic situation or problem is largely attributable to the problem trigger posed during the PBL learning. Hence, PBL lessons can be designed to facilitate the learning of mathematics among students. This was possible because the characteristics of PBL such as learning collaboratively in small groups, activating prior knowledge through group discussion, having a teacher to facilitate learning and having resources at hand to help them solve the given problem were in line with students' cognitive architecture (Schmidt, Loyens, van Gog & Paas, 2006; Hmelo-Silver, Duncan, Woods & Chinn, 2007). Hence, PBL lessons can be designed to facilitate the learning of mathematics in both secondary schools and higher learning.

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