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A Comparative Study of the Effect of Problem Based Learning and Traditional Learning Approaches on Students' Knowledge Acquisition

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This paper investigates the effect of Problem Based Learning (PBL) compared to conventional approach, on students' knowledge acquisition, specific to concepts, principles, and procedures. This study employed an experiment, a pre-test, and a post-test, with control group designs. Participants comprised 53 first semester electrical engineering undergraduate students, who are attending the Electrical Technology (ET101) module. Participants completed a set of pre-test and a set of post-test multiple choice questions, covering a two-unit syllabus after ten weeks of treatment. Results suggested that student within the PBL group outperformed their counterparts in knowledge acquisition of principles and procedures. However, students using the conventional approach performed much better in knowledge acquisition of concepts. In terms of the whole structure of concepts, principles, and procedures, PBL enhanced students' knowledge acquisition in the electrical engineering course, compared to the use of conventional approach. This study also discusses the implication of PBL within engineering education.

Keywords: Problem Based Learning; engineering education; electrical engineering; knowledge acquisition

1. Introduction

With recent developments in the field of engineering, providers of engineering education should understand the needs of the profession as well as problems associated with workplace. Graduates must be able to conceptually understand a problem, and be capable of applying their knowledge to solve an actual complex engineering problem effectively. One popular method which can address the needs of the engineering workplace requirements is by using PBL [1, 2]. This method has been widely claimed to be capable of promoting students' learning, especially enhancing knowledge acquisition and stimulating students' ability to apply knowledge in real world situations. This assertion is clearly supported by several previous research findings in engineering disciplines, particularly electrical engineering [3, 4]. In fact, PBL is generally ideal for imparting epistemological competence, in the aspect of better knowledge understanding, application, and management, in solving a problem [5].

PBL is anchored in Students Centred Learning (SCL) concepts that follow the principles of constructivist learning theory [6, 7]. In this theory, process of knowledge acquisition is internally imposed by an individual, when the cognitive processes are situated in physical and social contexts [8]. In other words, knowledge is learnt in a socially mediated process, whereby students acquire many concepts during social interactions. The understanding of a new concept is formed based on both current and previous knowledge and experience [6].

In the current trend of research, knowledge acquisition is a common variable of interest in evaluating PBL effectiveness, which can be measured in specific manner. Sugrue [9] proposed an explicit method of assessing knowledge structure according to concepts, principles, and procedures. During instruction, it is important for students' learning to reach these three levels of knowledge structure; students learn concepts, understand principles, and apply specific concepts and principles to a condition. When students' learning reaches these three levels of knowledge structure, they internalise and configure that knowledge in their mind, which helps them to retain knowledge longer, so that it can be easily recalled in the future [10].

Although PBL has been widely accepted internationally and adopted within multiple educational disciplines, a review reveals a gap in determining the effects of PBL instruction on students' knowledge acquisition of concepts, principles, and procedures [10, 11]. This may be due to several predictors that are associated with PBL design and learning outcomes, such as the quality of problems design [12], the method of facilitation [13], and the strategy of assessment [10]. In this paper, we examine the effects of PBL on students' knowledge acquisition, in order to provide an insight into specific concepts, principles, and procedures, within the electrical engineering context. Based on the existing PBL models, a special design of PBL procedures was used, which

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focused on these predictors to stimulate students' knowledge acquisition. The experiment revealed that there was an increase in students' knowledge, indicating the effectiveness of PBL as an instructional method, compared to conventional approaches.

2. Problem Based Learning research

The PBL model of the McMaster's Medical School was the first one to be established in 1974 [14], since PBL was introduced at the McMaster's University in 1965 [15]. To date, PBL model has evolved and has been used worldwide, including Australia [16], Denmark [14], Iran [17], and Singapore [1]. PBL is a challenging and enjoyable learning approach [18], which has been formulated basing on the process of working towards understanding or resolving a problem [15]. During instruction, students solve a real-world problem (or simulation) in a physical work space. Students learn concepts and principles through the process of problem solving, based on specific learning goals [6].The authenticity of the actual problem motivates students' ability to apply and relate these concepts and principles to real-world situations [6]. Their interaction with the environment helps them to translate the concepts and principles learnt, into new work practices [19]. Subsequently, these concepts and principles are converted into procedural knowledge, when they reach a certain level of higher performance [20].

In PBL literature, several authors have agreed that *deep-content learning* is one of the PBL intended learning outcomes [7]. In fact, evidence suggests that students, who are engaged in *deep-content learning*, improve their ultimate learning outcomes [10, 21]. It is generally agreed that students' performance and learning outcomes are associated with PBL components (predictors). The quality of a problem determines students' *deep-content learning*. The explanation of this relationship is as the following: a student recognises concepts, such as electricity, voltage, current, and resistance; understands principles, such as the relationship between current and resistance; and applies procedures, such as Ohm's Law, Kirchhoff's Law, and Norton's Law [12]. In conventional approaches, where a lecture-based method is used, students learn concepts and principles through memorisation [10]; it might be difficult for the learning to reach the highest levels by rote method. Other components, such as the role of the facilitator [1] and the strategy of assessment [10], serve as supportive elements to students' knowledge acquisition.

A review of a recent experimental research reveals that most studies measured students' knowledge acquisition without specifying specific knowledge structures. The results show that students in PBL groups significantly increased their knowledge acquisition, compared to students using a conventional approach [22, 23]. Only a few researches reported the three levels of knowledge acquisition according to concepts, principles, and procedures. In this context, the majority of studies indicated that PBL contributed positively to students' knowledge acquisition, in the aspects of concepts and principles. For instance, a quasi-experiment by Capon and Kuhn [24] demonstrated that PBL students had better concept acquisition compared to their conventional counterparts. In a research undertaken by Bilgin et al. [25], the true experimental study indicated that PBL students outperformed their conventional counterparts in acquisition of concepts and principles, after ten hours of PBL treatments.

However, several other studies also demonstrated that PBL did not have more advantages than conventional learning approaches in students' knowledge acquisition of concepts and principles. This was indicated by a quasi-experimental study carried out by Dehkordi and Heydarnejad [17]. In this study, participants, comprising 40 students, demonstrated positive effects of PBL on their higher cognitive levels, such as application; but not on understanding levels, such as recalling concepts. Similar findings were also illustrated by Sendaq and Odabas [26].Their comparison of PBL with conventional approaches did not show any significant difference in students' knowledge acquisition of concepts and principles.

In a wider context of educational disciplines, either in a true or quasi-experimental study, the effectiveness of PBL in promoting the knowledge of procedures or applications seems inconclusive. Several evidences suggest that PBL does not enhance students' knowledge of procedures or applications, compared to the level achieved through conventional approaches. For example, a quasi-experimental study by Van Den Bossche et al. [27] found no-significant difference in students' knowledge of procedures or applications in a PBL Macroeconomic course; compared to their conventional counterparts. This finding was supported by Sanderson's [28] study of Sports Science. The students in PBL groups did not enhance their knowledge of procedures or applications after 15 weeks of PBL treatment, compared to students using conventional approaches.

Several studies demonstrated that PBL was more effective in constructing students' knowledge of procedures or applications, compared to conventional approaches. This was also indicated by Capon and Kuhn [24]; the students in PBL showed better knowledge of procedures or applications by demonstrating their ability to apply knowledge to a specific test case. This similar finding was also illustrated by Dehkordi and Heydarnejad [17].When compared to Bloom's taxonomy of cognitive domain, PBL appeared to be effective in promoting students' learning at higher cognitive levels of application and evaluation, but less effective at lower cognitive levels [29].

A systematic review in the medical field discovered that students in PBL gained slightly less factual knowledge of concepts and principles [11]. Furthermore, there was no convincing evidence to support the argument that PBL instructional approach improved students' knowledge and clinical performance [30]. From the perspectives of knowledge as a whole structure of concepts, principles, and procedures, Gijbel et al. [10] supported the notion that the systematic evidence on the effectiveness of PBL was more likely to be equivocal across multiple educational disciplines. This situation justifies the need for this research in engineering education.

3. Methodology

3.1 Research Design

Experimental, pre-test and post-tests, with control group design, were implemented in July 2011 among undergraduate students, who are attending Electrical Technology Module (ET101) in their first semester, at a Malaysian Polytechnic.

3.2 Participants

Participants, consisting of a total of 53 students, were selected according to a two-stage cluster sampling technique [31]. In the first stage of sampling, two out of twenty-two polytechnics were selected, namely Polytechnic A ($N = 27$) and Polytechnic B ($N = 26$). In the second stage of sampling, a class (element) in each of these polytechnics was randomly selected according to lecturers, without first studying the students' characteristics. These classes were randomly assigned to either the experimental (Polytechnic A) or the control group (Polytechnic B). Both groups of students were then exposed to ten weeks of instructions (PBL versus conventional approach).The students were given a pre-test in the first week and a post-test in the twelfth week. In this study, the homogeneity of the two classes was confirmed by the pre-test data, which were not significantly different (Levene's statistic = 0.777; $p = 0.383$).

3.3 Experimental procedures

The instructions used for this study involve two selected units of the Electrical Technology (ET101) module syllabus (Units 3 and 4):

- An Introduction to Electric Circuits.
- DC Equivalent Circuits and Network Theorems.

These two major units have a timeframe of 14 hours of lecture and 20 hours of laboratory practical, within a period of eight to ten weeks. In this study, the timeframe for these units of instruction was prearranged into ten weeks for both groups. Students were first given a pre-test before the treatment began and a post-test after completing ten-week treatment.

Control group instruction procedures: In brief, the procedures for the control group were retained according to the existing setting, (i.e. conventional approach). In teaching Units 3 and 4, the lecture was for a two-hour meeting session in the classroom coupled with an additional two-hour laboratory session within one week. In this case, the lecturer typically delivered information and facts, explained terms, symbols, concepts, and procedures. Students acted as passive learners. In certain learning topics, for instance, 'Kirchhoff's Law', the lecturer introduced the theorem before showing some examples of application and calculation on a whiteboard. Due to the nature of content of these topics, which contains a large number of concepts and principles, the teaching approach by lecturing has always been the primary method of instruction. This instruction continued for 10 weeks in parallel with the experimental group.

Experimental group instruction procedures: The procedures were appropriately designed based on the standard of PBL practice provided by Koschmann [32]. A framework from Arts et al. [33] was used, which contains the three dimensions that influence cognitive outcomes, namely task dimension, control dimension, and social dimension. A variety of steps and processes that are typically used in the existing pioneering models were studied, such as the Aalborg Model, McMaster Model, Republic Polytechnic Model, etc. These steps were summarised according to three key success factors, namely problem orientation, implementation method, and assessment strategy [34].

During ten-week PBL treatment, students were scheduled to solve five problems related to faulty electrical and electronic circuits. Students were scheduled to have a two-week problem solving period, in order to complete one cycle of the PBL procedures. The first week's sessions were generally devoted to groups receiving problem scenarios. The second week was devoted to assessment activities. The subject-centric problem (non-multidisciplinary) was used as a trigger [35] and a ten-minute mini-lecture was used to fill the gaps within the subject-centric problem [7].

During the first tutorial session, students were divided into heterogeneous groups consisting of four to five members each [14], according to previous test results. Students mixed well in each group although some of them appeared awkward. The first leader of the group was then appointed by the facilitator and the role was rotated among members for each PBL problem. All groups received the similar problem in the form of graphical and written scenario. In order to facilitate problem solving processes, each group was given several documents, including a problem analysis table, humanistic skills rubric, process skills rubric, and grading forms. In addition, a facilitator conducted a mini-lecture to introduce the problem, explain several important concepts, and the role of students. At this stage, students looked confident and they immediately began work to extract the problem in order to gain understanding.

During the time of problem solving, the floating facilitator concept was applied. The facilitator moved from one group to another, in order to monitor progress and give guidance, as well as ask some provoking questions to students through the process of understanding the problem [1, 7]. In this case, the facilitator was committed to perform the procedures according to the instruction manual provided. Students were a bit hesitant in solving the first problem, but were more confident and comfortable with the procedures for the next problems. In this study, students were encouraged to conduct independent self-studies [1] and independent group discussions in-between meeting sessions. Students were also encouraged to collaborate with relevant experts [14] outside tutorial sessions.

During the final meeting session, the major activities involved information sharing, assessment, and a process of giving feedback [36]. The groups took turns to present their solution proposals. These short presentations were conducted in group-based format, with all group members presenting their respective parts [14]. While one group was going presenting the solution, the remaining groups performed peer-assessments to evaluate the presenting group's performance according to several criteria including professionalism, teamwork, leadership, and communication skills. At the end of the presentation session, students were asked to rate their team members' performance, according to the rubric rating scale [37]. Students went through the process well and were excited to rate their teammates, especially in the aspect of team members corporation. The facilitator provided feedback to each group [7]. Finally, the facilitator and students generalised the learning experience, which was relevant to their learning outcomes.

3.4 Instruments

A set of Multiple Choice Question (MCQ) tests, consisting of 36 selected items, was developed to measure students' knowledge acquisition, according to concepts (e.g., current, resistance), principles (e.g., relationship of current and resistance), and procedures (e.g., using Ohm's law) [9]. In order to ensure the validity of the measurement, items were selected according to the module's intended learning outcomes (of the two topics), as well as the lecturers' consent. Finally, 12 questions were used to fairly measure each level of knowledge structure, based on the test specification table. The specific difficulty levels were based on Bloom's taxonomy [38], which was detailed according to McMillan [39]. The estimated internal consistency coefficient was 0.62, which was above the range of modest reliability (0.5 to 0.6), and deemed acceptable for the purpose of research [40].

4. Results

Three students (Experimental group = 2; Control group = 1) dropped out from the polytechnic, and one student form the control group did not attend the post-test. The remaining 49's completed pairs of data were included in the analysis. Within these, males were dominant representing 84% ($N = 41$) of the respondents, whilst females represented 16% ($N = 8$). However, gender was equally distributed in both groups. The majority of students were 18 years old except two students who were 19 years old and above.

A number of factors were held constant. These included the lecturers, students, polytechnic administration, instruction duration, and the topics of instruction. Groups variance were homogeneous, since both groups pre-tests on knowledge were not significantly different [$F(1, 46) = 1.75, p > 0.05$]. The descriptive statistic and Analysis of Covariance (ANCOVA) were used to analyse the completed pairs of data ($N = 49$). The results are given in Tables 1 and 2.

Table 1 indicates that the mean score for the post-tests on knowledge acquisition in the experimental group, exceeds the mean score of the control group, with 22.92 (SD = 4.09) and 20.25 (SD = 3.79),

Table 1. Mean and standard deviation of knowledge acquisition

Grouping	Mean score	S.D.
Experimental group		
Pre-test score	16.56	2.551
Post-test score	22.92	4.092
Control group		
Pre-test score	15.96	3.085
Post-test score	20.25	3.791

Table 2. ANCOVA for knowledge acquisition test scores

Source of variation	d.f.	Sum of squares	Mean square	F	Sig. level
Pre-test knowledge	1	280.487	280.487	28.554	0.000
Instructions	1	55.927	55.927	5.694	0.021
Error	46	451.853	9.823		
Total	49	23707.000			
Corrected total	48	819.633			

a. R Square = 0.449 (Adjusted R Squared = 0.425)

respectively. As shown in Table 2, further analysis indicates that knowledge acquisition is statistically significant [F (1, 46) = 5.69, $p < 0.05$], indicates a significant difference between groups on knowledge acquisition scores when controlling for pre-test knowledge acquisition score. Therefore, students taught using PBL scored higher on knowledge acquisition than the students taught using the conventional approach. The effect size (0.68) was medium, with a power of 0.32.

Detailed analysis was performed using Multivariate Analysis of Covariance (MANCOVA) to test specific knowledge acquisition according to knowledge structures. The post-test mean of concepts acquisition indicates that the control group (M = 8.17, $S.D$ = 1.83) scored higher than the experimental group (M = 7.80, SD = 2.12); but both groups were not statistically significantly different in mean concepts acquisition [F (1, 44) = 0.849, $p > 0.05$]. However, the post-test mean of principles acquisition in the experimental group (M = 7.52, SD = 1.74) was higher than the control group (M = 5.42, SD = 1.86). As a result, both groups were statistically significantly different in principles knowledge acquisition [F (1, 44) = 18.72, $p < 0.05$]. The effect size (1.17) was large with a power of 0.50. The post-test mean of procedures acquisition in the experimental group (M = 8.00, SD = 2.06) was also higher than the control group (M = 6.71, SD = 1.78). Further analysis indicates that both groups were statistically significantly different in mean procedures acquisition [F (1, 44) = 5.01, $p > 0.05$]. The effect size (1.21) was large with a power of 0.52. Details of each analysis are shown in Table 3.

5. Discussion

These findings reaffirm earlier studies, which support the premise that PBL significantly increases students' knowledge acquisition, compared to conventional approach [22, 23]. These findings concur with the theory that PBL enhances students' knowledge acquisition, as explained by previous researchers [6]. The theory states that in PBL environment, learning occurs when students attempt to solve problems. When students are faced with a cognitive conflict, they interact with the environment, and construct knowledge based on previous knowledge and experience. Specific knowledge is learnt based on specific learning goals during the time of problem solving [6].

From the viewpoint of specific knowledge structures, these findings suggest that PBL promotes student's knowledge acquisition of principles and procedures, compared to a conventional approach. This can be justified in regard to the learning approaches used in both methods. Many authors have proposed that specific approaches used in PBL promote students' *deep-content learning* [7], since the method improves the quality of PBL intended learning outcomes [21]. Concerning the sample of this study, students in PBL may engage in *deep-content learning* during the process of solving PBL problems, particularly during discussion sessions, brainstorming sessions, and debate sessions; intervals of interaction, reflection, feedback, and teaching each other [41]. Moreover, previous research suggests that students achieve *deep-content learning* when they are capable of understanding the rela-

Table 3. MANCOVA for concepts acquisition scores

Knowledge structure	Group	Mean (Post-test)	S.D.	F	Sig. level
Concepts	Experiment	7.80	2.121	0.849	0.362
	Control	8.17	1.834		
Principles	Experiment	7.52	1.735	18.724	0.000
	Control	5.42	1.863		
Procedures	Experiment	8.00	2.062	5.005	0.030
	Control	6.71	1.781		

tionship of concepts (principles) and applying them to a condition (knowledge of procedures) [20, 21].

Several previous PBL experimental researches reported positive findings on concepts and principles [3, 4, 27, 24, 25]. However, the results of this study contradict those previous findings in the aspect of concepts, but support the positive findings in the aspect of knowledge acquisition of principles. Concepts and principles are normally defined as declarative knowledge, which is 'know-that', while the knowledge of procedures is known as 'know-why' or 'know-how' [20]. From this perspective, students may learn declarative knowledge of electrical engineering as a separate element between concepts and principles. As explained by Sugrue [9], this is because a domain, such as electrical engineering content, has explicit concepts and principles. Thus, understanding the first level of individual concepts, such as resistance, current, and voltage, seems much easier. Understanding the relationships of these concepts (principles) is at the next level, which sometimes requires much more effort for students to achieve. However, these results reaffirm the meta-analysis findings of Gijbel et al. [10], where PBL enhances students' knowledge acquisition in the aspect of principles and procedures.

In this study, students in PBL performed better in knowledge acquisition, compared to students in conventional approach, in the aspect of understanding procedures. Several previous studies showed the same results [17, 24, 29]. Additionally, these findings also align with the purpose of PBL for epistemological competence, as highlighted by Savin-Baden [5]. However, in regard to the limitation of this study, there is doubt in the effectiveness of PBL when compared to a conventional approach; this is especially in promoting students' procedural knowledge in these two topics, the content of which is simple and straightforward procedural knowledge. This situation provided limited space for multidisciplinary learning for PBL students in their first year. In this case, PBL may not be efficient for procedural knowledge acquisition within the boundary of the subject-centric problem. The PBL problem should imply that the nature of a real world problem is typically complex, ill-structured, and involves a solution of multidisciplinary context [2]. Therefore, it is argued that PBL is more efficient for nurturing students' procedural knowledge during the later years of their course.

In addition, this study found that students in conventional approach did much better in concepts acquisition, and outperformed students in PBL. This finding is supported by results of several previous studies [11]. Students in conventional approach did better at memorising more concepts or facts, but their memory retention was less compared to students in PBL. The possible reason for this is that in PBL, students underwent a process of learning through group brainstorming and discussion sessions [1, 7]. The group participation and interaction enable the students to better understand certain concepts or facts. On the other hand, students in conventional approach underwent a process of learning through listening and memorisation, which might make it difficult for students to reach the next higher level.

6. Conclusions

Based on these findings, it is concluded that students taught by using PBL have better knowledge acquisition in the aspects of principles and procedures, compared to students taught by using the conventional approach. This result implies that the method of instruction should focus on the application of knowledge or 'know-how' or 'know-why', rather than focusing on 'know-what', which is being practised in the conventional approach. The ability to apply knowledge is one of the necessary competences in solving problems in an engineering workplace or environment. In this area, PBL is able to enhance students' ability to apply knowledge, even in a mock-up engineering problem that was proven in this study. However, this study limited to 10 weeks of treatment; a longitudinal study would be more appropriate for obtaining more significant and concrete results. Further research is also suggested to investigate students' knowledge retention with respect to concept, principles, and procedures. Knowledge retention is critical, in order to ensure that students internalise knowledge within their field of expertise.

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