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The effectiveness of problem-based learning in the web-based environment for the delivery of an undergraduate physics course

Hanafi Atan
Universiti Sains Malaysia, Malaysia *ahanafi@usm.my*

Fauziah Sulaiman
Universiti Sains Malaysia, Malaysia *geebots@yahoo.com*

Rozhan M Idrus
Universiti Sains Malaysia, Malaysia *rozhan@usm.my*

This paper reports the investigation of the effectiveness of Problem-Based Learning (PBL) within a web-based environment in the delivery of an undergraduate Physics course. The effectiveness was evaluated by comparing the performances and the perceptions of the sample students (n=67) using the web-based PBL and comparing the outcomes with those of the web-based Content-Based Learning (CBL). The comparative post-test performance analysis conducted using a student t-test statistical analysis ($p<0.05$) revealed that the experimental web-based PBL approach yielded better performances than the controlled CBL approach. Where perceptions were concerned, the analysis also revealed that students exposed to the web-based PBL approach responded more positively with their knowledge enhancement compared to students exposed to the web-based CBL approach.

Problem-based learning, web-based learning environment, physics education, constructivism, online learning

INTRODUCTION

Problem-Based Learning (PBL) is a total approach of education and involves a constructivist approach to learning (Harper-Marinick, 2001). It is a well-known alternative approach to traditional disciplinary-based professional educational program in higher education. The emphasis of PBL is that students learn through the process of solving so called 'real-world' problems. The features of PBL regarded as essential for enhancing student learning are learning in context, elaboration of knowledge through social interaction, emphasis on meta-cognitive reasoning and self-directed learning (Boud and Feletti, 1991; Norman and Schmidt, 1992). Using PBL, students acquire life-long learning skills which include the ability to find and make use of the appropriate learning resources. PBL is also a curriculum development and instructional system that simultaneously develops both problem solving strategies and learning by placing students in the active role of problem solvers confronted with practical problems in the workplace (Poon et al., 1997).

The advances of Computer Mediated Communication (CMC) present an enormous shift in the manner PBL is conducted. The provision of synchronous and asynchronous collaboration and the availability of enormous and ever expanding course related web-pages provide a new dimension to the PBL approach. The process of PBL that requires the individual to seek information and

knowledge to construct new understanding, meanings and concepts and the collaboration between peers towards the solution of authentic and real-world problems can be readily supported by current communication media based on the computer and ICT (McAlpine and Clement, 2001).

Apart from the role of CMC in supporting the process of conventional face-to-face PBL, attempts have also been carried out to incorporate the entirety of the PBL learning processes in the web-based learning environment suitable for the delivery of courses in open and distance learning (Poon, 1997; Taplin et al., 1999; Varanelli et al., 2001; Orill 2002; Koschman, 2002). In open and distance learning, there exists a spatial and time gap between students and teachers and the ability of CMC to surmount the physical and temporal constraints makes the web-based PBL approach for the course delivery particularly useful and advantageous. The web-based PBL involves a creation of instructional materials that facilitate problem presentation; the required self-investigations and analysis can be conducted through the online resources and the social interaction for peer-peer collaboration and student-teacher facilitation can likewise be easily performed through asynchronous forum boards or synchronous chats. The final presentation of the answers to the problem can also be easily conducted through the array of the educational media technology tools made available by CMC.

There have been several studies that attempt to evaluate the effectiveness of the web-based PBL. Carderoy and Copper (2000) reported that students perceive the web-based PBL to be motivating, providing access to greater richness of resources and developing collaborative networks; the skills that they subsequently acquire are appropriate for their future professional activities. Arts et al. (2002) revealed that with a higher degree of student control related to aspects such as contents, the instructional path, pace and feedback, the PBL approach contributes significantly to improved cognitive gains. Ronteltap and Eurelings (2002) highlighted that the combination of synchronous and asynchronous tools in the web-based PBL leads to deeper levels of information processing when students compose documents that represent their personal knowledge based on their research from online resources.

Despite the importance of the web-based PBL especially for the course delivery in distance and open learning, there is no known study that attempts to evaluate the effectiveness of this approach relative to the widely available online Content-Based Learning (CBL) both in terms of students' performances and perceptions. The present study, therefore, seeks to explore the relative effectiveness between these two approaches and in doing so, raised the following questions:

1. How effective is the web-based PBL compared to the web-based CBL in terms of the students' academic attainments?
2. How effective is the web-based PBL compared to the web-based CBL in terms of the students' perceptions?

The findings to the above research questions would provide valuable information to the institution regarding the instructional approach to be taken in the delivery of course materials through open and distance learning especially for science courses. Such an approach should help the institution to enhance and improve students' academic performances, increase knowledge retention among them and enable them to acquire the necessary skills to solve workplace related problems using the advances of the CMC technology available today.

THE DESIGN OF THE WEB PAGE

In order to examine the effectiveness of the web-based PBL in terms of the students' academic enhancement, two specially designed Web pages were developed and installed online. The first Web page was the Web page designed according to the PBL approach which acted as an

experimental Web page. The second Web page, designed according to the Content-Based Learning (CBL) approach, acted as a control Web page.

The PBL Web Page

For the experimental web-based PBL treatment, two separate Web pages were developed under the topics of *Black Body Radiation, Radiation Spectrum and the Theory of Stefan-Boltzmann* for Lesson 1 and *Wien's Law, The Rayleigh-Jeans's Theory and Planck's Law* for Lesson 2 in an undergraduate course at Universiti Sains Malaysia (USM). The design was adapted on the model suggested by Harper-Marinick (2001) and consisted of the following sequences of learning,

1. **Introductory information** – introducing the process of PBL and the role it should play to accomplish the learning tasks.
2. **Presentation of an ill-structured and real-world problem** – serves as the organising centre and context of learning.
3. **Online collaboration** – discussion among peers to propose the hypotheses and identification of learning issues. The group subsequently delegated responsibilities to each individual to find out more information about learning issues.
4. **Online resources –** each individual was engaged in individual online research on the learning issue assigned to him.
5. **Follow-up online collaboration** – students reported on the research done, identifying overlapping issues, and discussing the new hypotheses and learning issues.
6. **Solution to the problem -** students collectively agreed upon the solution of the problem and the plan of the presentation.

The PBL web-pages can be accessed through the following URL addresses:

a) Lesson 1: http//pppjj.usm.my/Fizik/sjh_3/default.html ; and

b) Lesson 2: http//pppjj.usm.my/Fizik/sjh_4/default.html

The CBL Web Page

For the CBL treatment, two separate Web pages were developed containing the same topics as those developed utilising the PBL approach, i.e., *Black Body Radiation, Radiation Spectrum* and *the Theory of Stefan-Boltzmann* and *Wien's Law, The Rayleigh-Jeans's Theory* and *Planck's Law*, each for Lesson 1 and Lesson 2 respectively. The design was adapted from the Dick and Carrey Model (1996). It is a course material presentation that follows the objectivist principle of learning. Its sequence of learning is as follows:

1. **Introduction to the course content** – a brief introduction of the course contents.
2. **Learning objectives -** the students were given the expected learning objectives to be achieved at the end of the treatment
3. **Material presentation** – the material was segmented and the presentation of content was from a low level to a high level of understanding.
4. **Sample questions and answers –** the solved problems were shown to the students to enhance their understanding.
5. **Summary --** summarising the course content.
6. **Evaluation --** sample questions for self-evaluation.

The CBL Web pages can be accessed through the following URL addresses:

a) Lesson 1: URL:http//pppjj.usm.my/Fizik/sjh_1/default.html ; and

b) Lesson 2: URL:http//pppjj.usm.my/Fizik/sjh_2/default.html

RESEARCH METHODS

The sample in the present study consisted of the first year undergraduate Physics students enrolled in ZCT 104 – Modern Physics, a course offered in the first semester of the 2002/2003 academic session by the School of Physics, Universiti Sains Malaysia (USM). From a total of 457 students enrolled in this course, 67 were randomly selected for this study. The experimental design of the study involved a separation of the randomly selected sample into two groups and these groups were exposed to two separate learning sessions, Session A and Session B. Each session consisted of two lessons, Lesson 1 and Lesson 2 incorporating the PBL and CBL approaches. The schematic representation of the experimental design is given in Figure 1.

The experimental design that was used was the rotational-group design proposed by Mouly (1963). In this design, each sample was required to be exposed to the experimental as well as to the control treatments. This rotational procedure enabled the elimination of uncertainty due to the variations of the sample. The measured dependent variables in this study were the knowledge enhancement both in terms of the academic performances and students' perceptions. The independent variables were the instructional design of the web page, one utilising the PBL approach and the other utilising the CBL approach. Other moderating variables, such as computer competency, were found to indicate no statistical differences ($p<0.05$) between the experimental and the control samples. The period of the exposure between the two groups was equally fixed at $1^1/_2$ hours and the course content curriculum was also similar.

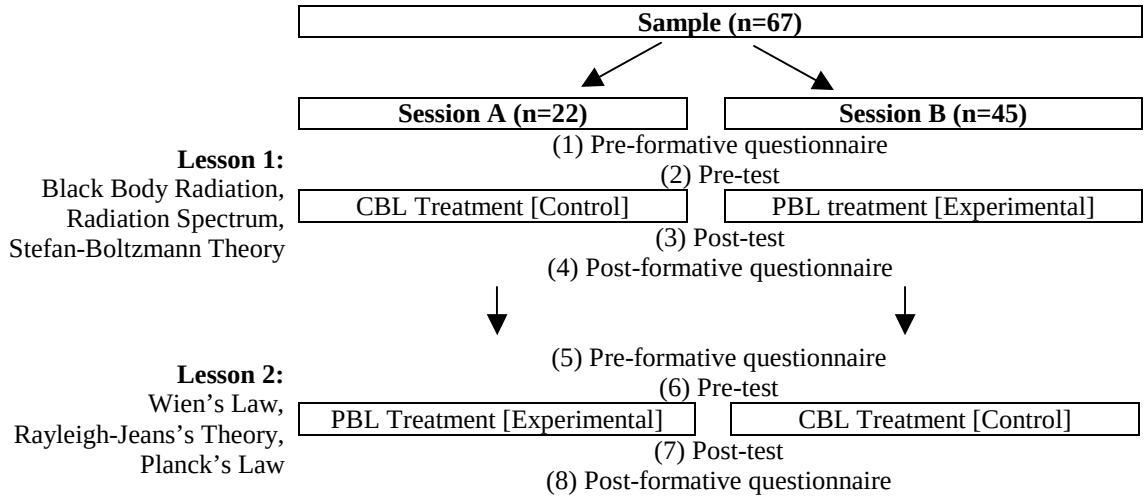

Figure 1. The experimental design

The instruments used to determine the dependent variables were the post-test and the post-formative questionnaire. The post-test consisted of 5 to 7 subjective questions, assessing and evaluating the students' actual academic attainments and understanding pertaining to the respective lesson's learning objectives with the given maximum mark of 100. The formative questionnaire required students to indicate their understanding of items relating to the course content material of each respective tutorial. Each item was accompanied by a four point Likert scale, with 1=denoting no knowledge, 2=little knowledge, 3=moderate knowledge, and 4=good knowledge.

A pilot testing involving a different sample was also carried out to ensure the internal consistency of the formative questionnaire as well to improve the design of the Web pages for the smooth running of the actual experiment. The data collected were analysed using a standard statistical package. The student t-test was in turn used to make the comparative analysis and the null hypothesis was that there was no difference in the students' knowledge enhancement both in terms of their perceptions as well as performances between the CBL and the PBL approaches.

RESULTS AND DISCUSSION

Table 1 shows the comparative analysis between the means of the pre-test marks of the CBL and PBL approaches. As can been seen, there was no difference ($p<0.05$) between the mean marks of the two approaches, implying that both groups were homogeneous in terms of the background knowledge before the treatments were carried out. Any indifference that might have existed in the background knowledge between the samples prior to the treatment would not have any influence on the results of the comparative academic performances and perceptual analysis.

Table 1. Comparative analysis between the mean marks of the CBL and PBL pre-tests for Lesson 1 and Lesson 2

	Session A		Session B		Mean Difference	t-test	p
	%	SD	%	SD			
	Control CBL (n=22)		Experimental PBL (n=45)				
Pre-test (Lesson 1)	18.36	11.32	21.80	11.62	3.44	1.314	0.256
	Experimental PBL (n=22)		Control CBL (n=45)				
Pre-test (Lesson 2)	9.80	4.19	11.14	10.10	1.20	-0.764	0.446

The comparative academic performance analysis was carried out with a comparison between the means of the post-test marks between the CBL and the PBL approaches. This analysis is shown in Table 2. As can been seen in Lesson 1, there was a significant difference between the mean marks of the PBL and CBL, with the PBL approach recording a higher mark. However, no significance difference was recorded between the two approaches in the Lesson 2. These results are an indication that the PBL approaches yielded a better students' academic performance or at the very least matched that of the CBL approach.

Table 2. Comparative analysis between the mean marks of the post-tests for the CBL and PBL approaches for Lesson 1 and Lesson 2

	Session A		Session B		Mean Difference	t-test	p
	%	SD	%	SD			
	Control CBL (n=22)		Experimental PBL (n=45)				
Post-test (Lesson 1)	66.91	6.05	73.56	9.94	6.65	8.301	0.05*
	Experimental PBL (n=22)		Control CBL (n=45)				
Post-test (Lesson 2)	71.36	14.37	72.59	6.25	1.23	0.151	0.699

*significant level $p<0.05$

The enhancement of the students' knowledge prior to and after the treatments between the two approaches is shown in Figure 2 and Figure 3 for Lesson 1 and Lesson 2 respectively. It is evident that both approaches produced a considerable enhancement in terms of the knowledge constructed by the students. However, when the two approaches are compared, it is evident that the PBL approach yielded a superior learning enhancement.

The students' perceptual analysis in terms of the knowledge enhancement was carried out by comparing the post-formative questionnaire between the CBL approach with that of the PBL approach. The results of the analysis are shown in Table 3 and Table 4 for Lesson 1 and Lesson 2 respectively. The results in Table 3 showed no significant difference between the CBL and the PBL approaches. Nevertheless, it is interesting to note that all the items recorded higher mean values for the PBL approaches. The results in Table 4 recorded significant differences for Items 1 and 3 with higher mean values for the PBL approach. In contrast, only Item 6 recorded significant

differences with higher mean values for the CBL approach. Other items recorded no significant differences and as indicated in Table 3, all of them registered higher mean values for the PBL approach. It is, therefore, quite evident that these results highlighted the advantageous features of the PBL approach as perceived by the students. The higher knowledge enhancement through the PBL approach perceived by them complimented the above findings of superior academic performances following the application of the PBL approach compared to the CBL approach.

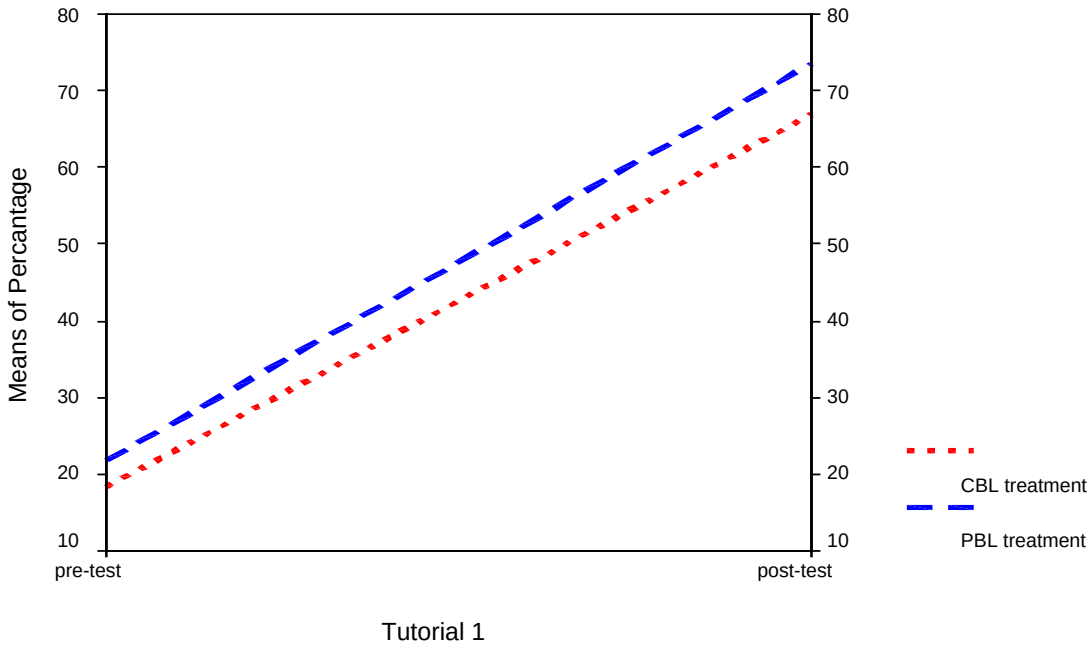

Figure 2. Graph showing the enhancement of the mean marks between the pre-test and the post-test following the PBL and CBL treatments for Lesson 1

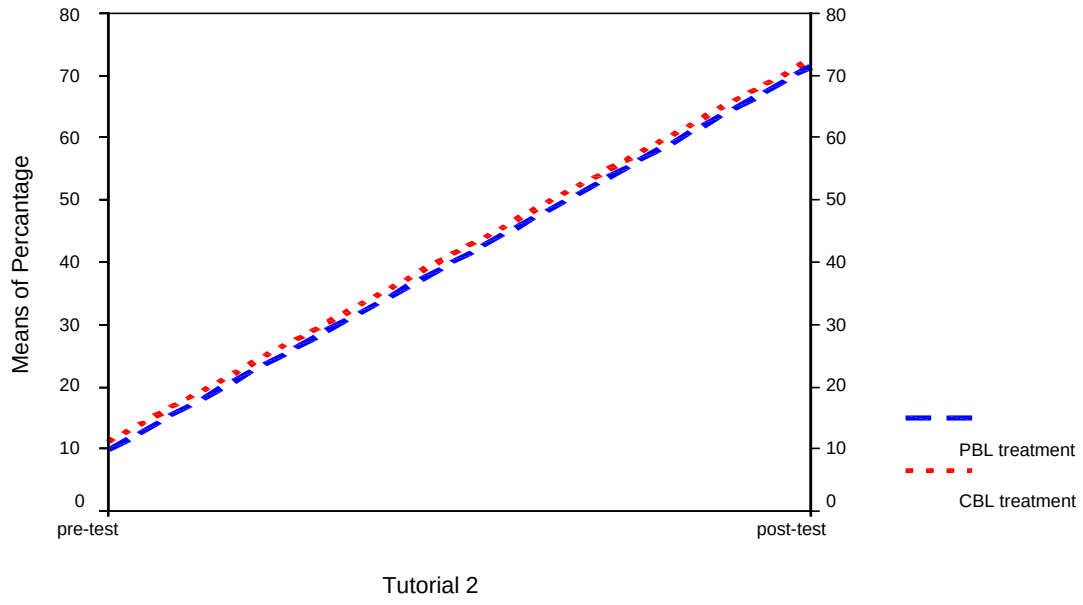

Figure 3. Graph shows means of percentages for the pre-test and post-test for the PBL and CBL treatments in Lesson 2

It is clear that the PBL approach brings about enhanced educational practices as far as the web-based course delivery is concerned. The inherent characteristic features of the PBL approach (namely, of learning in context, elaboration of knowledge through social interaction, an emphasis

on meta-cognitive reasoning and self-directed learning) can be easily supported by the current CMC technology leading to improved learning outcomes.

Table 3. Post-formative comparative analysis between control group (CBL; n=22) and experimental group (PBL; n=45) for Lesson 1

Item	CBL (mean)	PBL (mean)	t-test	p
The concept of the black body radiation	3.0909 (0.426)	3.0222 (0.839)	0.361	0.719
The characteristics of black body such as the spectrum, peak in light intensity graph and the temperature correlation of the black body radiation	3.0455 (0.375)	3.1778 (0.716)	-0.812	0.420
Application of the light intensity equation and the black body temperature equation	3.0000 (0.535)	3.2667 (0.837)	-1.362	0.178
The concept Stefan-Boltzmann temperature distribution	2.9091 (0.426)	3.1333 (0.869)	-1.142	0.258
Application of the Stefan-Boltzmann equation	2.9545 (0.486)	3.1778 (0.777)	-1.232	0.222

Table 4. Post formative comparative analysis between the control group (CBL; n=45) with the experimental group (PBL; n=22) for Lesson 2

Item	CBL (mean)	PBL (mean)	t-test	p
The concept of Wien's Theory	3.000 (0.426)	3.318 (0.477)	-2.759	0.008*
Application of Wein Equation	3.1778 (0.614)	3.454 (0.510)	-1.827	0.072
The concept of Rayleigh-Jeans Theory	2.9778 (0.452)	3.3182 (0.568)	-2.658	0.010*
Application of Rayleigh-Jeans Equation	3.088 (0.557)	3.227 (0.429)	-1.025	0.309
The concept of Planck's Theory	3.044 (0.520)	3.227 (0.528)	-1.344	0.184
Application of Planck's Equation	3.111 (0.682)	2.636 (0.727)	2.620	0.011*

*significant level $p < 0.05$.

CONCLUSIONS

This study has elucidated the effectiveness of the web-based PBL approach both in terms of the students' academic performances and perceptions and compared it to the commonly available web-based CBL approach. The results show that the web-based PBL approach has the ability to out-perform the web-based CBL approach in both aspects studied. This implies that not only do the students perform better but they also perceive that they have acquired better understanding of the concepts they are supposed to learn. Other advantageous features of the PBL approach have also been indicated, such as learning through social interaction, acquisition of kills in meta-cognitive reasoning and proficiency in problem solving in the workplace context. As such, efforts should be taken by the institutions of open and distance learning to consider the web-based PBL approach as one of the mechanisms for the delivery of courses in their educational program.

REFERENCES

Arts J.A.R., Gijselaers W.H. and Segers, M.S.R. (2002). Cognitive effects of an authentic computer-supported, problem-based learning environment. *Instructional Science,* 30, 465-495.

Boud, D. and Feletti, G. (1991). *The Challenge of PBL*. London: Kogan.

Corderoy, R.M. and Copper, P. (2000). The development of an online Problem Based Learning Environment to support the development of engineering professional practice skills: the Virtual Engineering Consultancy Company (VECC). *Indian Journal of Open Learning*, 9(3), 339-350.

Dick, W. and Carey, L. (1996). *The Systematic Design of Instruction*. (4th Edition). New York: Harper Collins Publishing.

Harper-Marinick, M. (2001). Engaging students in problem-based learning. Maricopa Centre for Learning and Instruction. [Online]. http://www.mcli.dist.maricopa.edu/forum/spr01/t11.html [Accessed 23 June, 2005].

Koschmann, T. (2002). Introduction to special issues on studying collaboration on distributed PBL environments. *Distance Education*, 23(1), 5-9.

MacAlpine, I and Clements, R. (2001). Problem-based learning in the design of a multimedia project. *Australian Journal of Educational Technology*, 17(2), 115-130.

Norman, G.R. and Schmidt, H.G. (1992). The psychological basis of problem based learning: A review of the evidence. *Academic Medicine* 67, 557-565.

Orill, C.H. (2002). Supporting on-line PBL: Design considerations for supporting distributed problem solving. *Distance Education*, 23 (1), 41-57.

Poon, S.K., Reed, S. and Tang, C. (1997). Problem-based learning in distance education. *Proceedings of the 5th International Conference on Modern Industrial Training,* Jinan, China. 593-600. [Online]. http://www.ic.pdyu.edu.hk/ocss/papers/PBL.pdf [Accessed June 13, 2004].

Rontelap F. and Eurelings A. (2002). Activity and interactions in an electronic learning environment for problem-based learning. *Distance Education*, 23(1), 11-22.

Taplin, M., Leung, A., Chan M.S., Wan, C.W., Kuen, K.S., Lam, M., Mok, V., Lee, A.N.O., Siaw, I.R.C., Swearse, B. and Tsui, C. (1999). The role of problem-based learning in distance education. In D. Xingfu (Ed.) *Proceedings of the 13th Annual Conference of Asian Association of Open Universities*, pp 175-189, Beijing, 14-17 October, Vol 2.

Varanelli, A., Baugher, D. and Hall, J. (2001). A problem-based, collaboration learning approach to distance education at the MBA level:e.MBA@PACE. *Business, Education and Technology Journal*, Spring, 36-44.