If You Think PBL Is Right for Your Students, Think Again.

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Abstract

Problem based learning (PBL) has been widely practised and extensively researched in a variety of disciplines for over past four decades. However, its evidence of effectiveness still remains inconclusive. This literature review paper debates the effectiveness of problem-based learning on learners' academic performance. Specifically, the discussion in this paper puts the focus on the basic concept of PBL and the effectiveness of PBL based on the existing research findings. Apart from that, cognitive load theory will be discussed as it is generally believed that cognitive load induced by any learning strategy has an impact on learner's performance. The effectiveness of PBL from the perspective of Cognitive Load Theory will be presented. In addition, this paper also puts forward some theoretical ideas on when to ultilise PBL during the process of teaching and learning, and how the implementation of PBL can be improved by integrating with other learning strategies.

Key words: Problem-based learning, cognitive load, effectiveness, mental effort

1   Introduction

Job markets are becoming increasingly competitive, particularly in the manufacturing sector, due to the technological developments and rising education and skill requirements (Lai & Yap, 2004). Individuals equipped only with the basic skills, such as reading, writing and numeracy, will face difficulty in securing a job. Apart from these basic skills, one must also master the skills of communication, critical and creative thinking and, more importantly, problem solving in order to be capable of responding to a problem quickly, correctly, and with little or no supervision (Jonassen, 2004).

Gale, Wojan, and Olmsted (2002) have conducted a survey of over 3,000 USA manufacturing establishments to explore the associations between worker skill requirements and the use of manufacturing and telecommunication technologies, work organisation, and other management practise. The survey reported an increasing demand on worker's problem solving skills in addition to computer and interpersonal skills in manufacturing sector. Similarly, Mohamed Rashid and Mohd Nasir (2003) also reported that the problem solving skill, along with

teamwork and communication skills, are listed at the top of the list of competencies needed for employment in manufacturing sector.

The above examples show the significance of problem solving skills for the manufacturing workforce. As even those who are well-schooled in the basic academic skills (e.g., maths and reading) might still lack the problem solving skills sought by cutting-edge manufacturing firms, there are strong reasons to suggest that pragmatic and effective actions should be undertaken by those institutions responsible for training the next generation of highly skilled workers. Given that the technical workers in the manufacturing sectors are often asked to solve problems, there is an obvious need for instructional designers to develop methods to help students become more effective problem solvers. To this end, a number of researchers (e.g., Hmelo-Silver, 2012; Bransford, Brown & Cocking, 2000; Savery, 2006) have suggested that learning through real life problems might be an effective way of acquiring problem solving skills. Instructionally, this can be accomplished through PBL, which promotes problem solving skill acquisition through the development of self-learning strategies, while requiring students to apply knowledge and solution strategies to new situations (Blumberg, 2000; Mergendoller, Maxwell, & Bellisimo, 2001).

2   The Concept of Problem-Based Learning

PBL is gaining wider acceptance across the world of education; however, it is not always clear what constitute PBL, as it has been used to designate heterogeneous forms of learning in various educational institutions (Hmelo-Silver, 2012; Maudsley, 1999). Different institutions adopted their own model of PBL and defined differently based on their modified model. For this reason, it is fairly difficult to find a precise definition of PBL (Michel, Bischof & Jakobs, 2002). This is partially due to the ambiguous understanding of PBL by some educationists and researchers, and also due to the modification of PBL to accommodate different contexts and disciplines (Savery, 2006). The use of PBL varies markedly not only between disciplines, but also within the same discipline. For example, some institutions have completely switched their curriculum to PBL (e.g., Hallinger & Lu, 2012), others have used various hybrid approaches utilising both PBL and lecture-based learning (e.g., Samarasekera & Karunathilake, 2011), while some have implemented PBL only in individual courses (Padmavathy & Mareesh, 2013) and used technological enriched learning environment (e.g., Liu, Wivagg, Geurtz & Chang, 2012).

In reviewing the origins of PBL, its pioneers, Barrows and Tamblyn (1980), refer to PBL as:

> *"the learning that results from the process of working toward the understanding or resolution of a problem. The problem is encountered first in the learning process and serves as a focus or stimulus for the application of problem-solving or reasoning skills, as well as for the search for or study of information or knowledge needed to understand the mechanisms responsible for the problem and how it might resolved."*
>
> (p. 18)

For Barrows and Tamblyn, the idea behind PBL is that the problem drives the learning. That is, students are exposed to a problem before they develop the relevant domain knowledge on their

own. The students are expected to gain knowledge through the process of solving the given problem, which functions as a stimulus to encourage students' thinking and engagement through the entire process of learning. It is important to note that teacher is not the primary source of information and that teacher-centred lecturing approach is not used in PBL; in fact, students are free to seek relevant information from various sources.

Specifically, PBL begins by requiring students to work on a real life problem, which is usually complex, ill-structured, and involves interdisciplinary contents. At this stage, students commonly have limited prior domain knowledge, because the domain knowledge has not yet been imparted to them. During the problem solving process, students attempt to identify the nature of the problem, which is preferably done in a group setting guided by a facilitator. After recognising the goal of the problem, the students have to develop and formulate some feasible strategies to solve the problem and determine what information they need to collect and which methodology they should apply. In the process of finding solutions, the students continue collecting and processing information that might be related to the problem. Eventually, all students are required to discuss and evaluate their final solutions with the assistance of a facilitator. Through this process, the students may develop profound and relevant knowledge of the subject area (Cocke, Li, Dede, & Alicli, 2002; Ertmer & Simons, 2006; Hong, Chu, & Liu, 2005). In short, the operational concept of PBL can be summarised into five processes: first, identification of a problem; second, formulation of a strategy; third, collection of information; forth, problem solving; and lastly, evaluation of solutions.

Despite the emergence of a variety of PBL models, Barrows (2002) has recently identified four primary elements that constitute a minimum standard for PBL. Those elements are:

- *Student-centred learning approach:*
  In PBL, students determine the main issue of the problem on their own and decide what has to be learned in order to solve it. Thus, it is the responsibility of the students to acquire any missing knowledge that is needed to solve a given problem.

- *Using ill-structured problems in learning:*
  Ill-structured problems may have more than one correct solution, which tends to motivate students to search for additional possible solutions. Ill-structured problems are also used to stimulate learners to think critically and analytically about the causes of and the solutions for the problem.

- *Facilitator supports:*
  Instead of lecturing and spoon-feeding, a teacher guides students by leading them towards thinking creatively during problem solving. The teacher is expected to inspire students with meta-cognitive questions and, in turn, gradually reduce guidance.

- *Authentic problems:*
  Authentic problems are derived from the real world and usually involve multiple disciplines. Such problems require students to study multiples topics in order to solve the problems successfully, which in turn might help develop a well-defined, well-organised, and applicable cognitive structure of knowledge.

PBL is seen by some as an effective didactical method to foster knowledge and problem solving skill acquisition, particularly in medical education (McParland, Noble, & Livingston, 2004; Mergendoller, Maxwell, & Bellisimo, 2006). However, mixed past results make it difficult to come to a conclusive judgement about PBL. The following section will focus on the issue concerning the effectiveness of PBL.

3   Effectiveness of Problem-Based Learning

Over the past few decades, substantial research has been conducted to evaluate the effectiveness of PBL. Some previous research put the stress on examining the effectiveness of PBL itself, without comparing it with other learning strategies (see Gallagher, & Gallagher, 2013; Mergendoller, Maxwell, & Bellisimo, 2001); while other studies employ comparative methods to investigate the impacts of PBL on learning outcomes in comparison to other pedagogical strategies. For example, Moreno-Lopez, Somacarrera-Perez, Diaz-Rodriguez, Campo-Trapero, and Cano-Sanchez, (2009) conducted a study to evaluate the academic performance of PBL and lecture-based learning in Dentistry. They reported that students' academic results were better when PBL was employed, in comparison to lecture-based learning. Similarly, Li, Li, Li, Chen, Xie, Li and Chen (2013) has also conducted a study to compare the effects of PBL and lecture-based learning methods on academic results and student perceptions in a dermatology course. The research showed that compared to those receiving lectures only, all PBL participants had better results for written examination, clinical examination and overall performance.

Although the effectiveness of PBL is apparently positive, one should note that most of the studies were based on medical education (Hmelo-Silver, 2004; Pross, 2005). It is arguable whether or not those research outcomes would prove representative for students from other disciplines. According Mergendoller, Maxwell, and Bellisimo (2000) and Visser (2002), the research findings from the application of PBL in medical school context should not be generalised to other students because students in medical schools are often a relatively elite group due to typically the strict admissions standards. Therefore, students enrolled to medical schools are likely to have higher formal educational achievement as well as academic skills than the general school population. This trend may play a significant role in determining the impact of any pedagogy on the cognitive and metacognitive development of the students. This issue has triggered a significant debate over whether the 'classic version' of problem-based learning, which is based on medical education, is applicable to other disciplines, such as manufacturing technology.

On the other side of the coin, the notion that PBL enhances student learning performance remains in dispute, as a volume of contradictory findings found from the literature illustrates (e.g., Berkson, 1993; Colliver, 2000). For instance, Michel, Bischof, and Jakobs, (2002) concluded that "the results demonstrate that factual knowledge was similar in both groups (PBL and lecture-based learning) at the end of their classes" (p.169). This conclusion is consistent with several studies that have reported no significant differences between problem-based and lecture-based learning in terms of students' learning performance (see Cruickshank & Olander, 2002;

Dyke, Jamrozik, & Plant, 2001). Additionally, three meta-analyses have been conducted to compare the effectiveness of problem-based and lecture-based learning (see Albanese & Mitchell, 1993; Culver, 2000; Vernon & Blake, 1993). The findings from these meta-analyses have unanimously concluded that there was no statistically significant difference between the two learning approaches in either factual knowledge acquisition or clinical performance. The findings from the aforementioned meta-analyses are supported by a great number of other studies that found no convincing evidence that PBL improves a student's knowledge base and clinical performance. On the other hand, the analysis of comparing PBL and lecture-based learning done by Dochy, Segers, Van den Bossche, and Gijbels, (2003) indicates that the results on skills were positive, but the results on knowledge were weak.

In addition to the inconsistent and incomplete knowledge about the effectiveness of PBL approach, Newman (2003) has reported in his review and meta-analysis that:

> *"the limited high quality evidence available from existing reviews does not provide robust evidence about the effectiveness of different kinds of PBL in different contexts with different student groups."*

<div align="right">(p. 6)</div>

In his review of literature, Newman discovered that most of the studies were methodologically flawed; for instance, a number of research papers provide insufficient data to calculate effect size. Albanese (2000) also commented on some PBL research design flaws, such as lack of randomisation of experiment subjects, variation in exposure to the experimental treatment and a prolonged period of experimentation, which would allow extraneous variables to affect the outcomes. Similar with Newman's findings, Sanson-Fisher and Lynagh (2005) assert that some of the previous research was methodologically flawed and cannot be used to argue the superiority of PBL.

In addition to these methodological defects, the PBL research findings might have also been affected by the lack of instrument validity and reliability. It has been argued that some measurement tools were insufficiently sensitive and incapable of measuring the intended learning outcomes in the studies (Berkson, 1993). This commonly resulted from the practice of utilising measurement instruments found in research articles, books, and on the internet without thoroughly verifying their validity and reliability (Belland, French, & Ertmer, 2009). It is unfortunate that the quality of the measurement instruments, sometimes, has not been given sufficient intention by the previous users. Using low validity and unreliable instruments may have directly impacted the result, which could have brought about a false interpretation of the result and led to an inaccurate conclusion.

Due to the inconsistency and low quality of evidence that PBL works better than conventional instructional approach, one could assume that there is no superiority of PBL approach in terms of transfer performance. Thus, it is worth exploring some of the possible explanations for the lack of performance of PBL.

One of the possible reasons could be that the theoretical foundations that underpin PBL are insufficiently well-established. Barrows (2000), a pioneer of PBL, explains that he and the other

developers of the original McMaster PBL curriculum had no background in educational psychology or cognitive science. They simply presumed that learning through solving clinical problems in small groups would make medical education more interesting and relevant for their students. Additionally, the philosophical and theoretical underpinnings of PBL were not explicit in the early PBL literature (Rideout & Carpio, 2001). As PBL has expanded into other disciplines, education theorists – who often place emphasis on different aspects of teaching and learning – have begun to derive a theoretical justification for this method of learning (Newman, 2003). Essentially, the PBL approach has begun to build upon the base of constructivism and socio-cultural theories within the education paradigm (Camp, 1996; Hmelo & Evensen, 2000; Savery & Duffy, 1995). Constructivist learning emphasises that human learns by building new knowledge upon a previous foundation of knowledge. Problems used in PBL create a state of disequilibrium, which cannot be solved until a new cognitive structure is constructed. This view of learning sharply contrasts with one in which learning is the passive transmission of information from one individual to another. Socio-cultural theory, on the other hand, focuses on the dialectic process between the individual and society, and the effect of social interaction, language, and culture on learning. This theory emphasises the influence of social interaction on human thinking and cognitive processes. Group problem solving processes and group discussion in PBL provide a framework for social interaction, which is subsequently transformed into internal mental process.

In addition to these two theoretical foundations, Poikela and Poikela (1997) proposed another two additional theoretical conceptions of learning related to PBL, namely, behaviourism and experientialism. The fundamental concepts of behaviourism are 'stimulus' and 'conditioning'. Since the focus of PBL is on reflection (stimulus-response system of learning), the authors assert that PBL is a behaviouristic method of learning. Alternatively, the concept of experientialism maintains that cognition objectives are achieved by reflecting on experiences. That is, reaching the learning objective is dependent upon the learner's ability to reflect upon his/her experience, observations, cognition and experimentation in learning. Therefore, for Poikela and Poikela, the key to PBL is reflection, which provides an additional source of theoretical support for PBL.

There are at least two issues raised by the abovementioned arguments pertaining to the theoretical underpinnings of PBL. First, there is no firm agreement on which theoretical foundation should be applied to underpin PBL. The diversity of theoretical foundations applied to PBL in the literature clearly indicates that the learning theory supporting PBL is still shaky. Second, the theories derived by various PBL users do not illustrate how a learner's cognitive structure is organised during the learning phase. In other words, PBL is implemented with no reference to cognitive architecture or human memory architecture. As Kirschner, Sweller and Clark (2006) said, "any instructional procedure that ignores the structures that constitute human cognitive architecture is not likely to be effective" (p. 76). In PBL, students are first presented with a real-world and ill-structured problem, which integrates multidisciplinary knowledge, before the learning of content knowledge takes place (Savery, 2006). Ill-structured problems are complex problems that cannot be solved by a simple algorithm and are not necessarily to have only one absolute correct answer (Hmelo-Silver & Barrows, 2006). That means, the students must interact with a great number of variables to solve the problem; such tasks consume huge working memory resources and leave little space for students to learn new things. This is to say that heavy working memory load does not contribute to the accumulation of new information in

long-term memory, due to the congestion of interacting elements, and this may not promote learning eventually (Sweller, van Merriënboer, & Paas, 1998).

To enhance learning, it is important to reduce working memory load. In other words, working memory needs to be freed up to allow beneficial cognitive activities taking place, such as the organisation of information and the construction of new knowledge. To deal with this issue, PBL strategy needs to undergo some modifications, especially from the aspect of problem presentation which can induce the saturation of working memory.

4 Cognitive Load Theory

Based on CLT, the working memory capacity in human brain is limited in the number of elements it can hold simultaneously and it places high demands on working memory when a task that contains high number of interacting elements that have to be processed in working memory simultaneously. On the other hand, long-term memory provides humans with the ability to vastly expand the processing ability. This memory allows incorporation of multiple elements of information into a single element with a specific function (Pass, Renkl, & Sweller, 2003). In other words, the long-term memory is sophisticated cognitive structure that allows a person to perform high level of skills such as analysing and problem solving.

Recent theoretical developments have conceptualised the idea of cognitive load further by distinguishing between intrinsic, extraneous, and germane load (Pass, Renkl, & Sweller, 2003). Intrinsic load refers to the complexity of learning contents or instructional task in relation to a learner's prior knowledge and depends on the number of interacting elements that have to be processed simultaneously and kept active in working memory during the learning process (Sweller, 1988). For instance, problem-solving task will require processing of numerous information elements and it is more complex compared to memorising factual information. Thus, problem-solving task imposes more intrinsic cognitive load.

Extraneous load is referred to as an ineffective cognitive load because this load is unnecessary and it interferes with schema acquisition and automation (Paas, Renkl, & Sweller, 2003). Extraneous load is usually imposed by the design of instructional task or by the activity which is not directly related to learning or schema acquisition. For example, any instructional task that requires students to look for problem solution and search for reasoning of an explanation is likely to impose a heavy extraneous load because working memory resource must be used for activities that are not relevant to schema acquisition. Paas and Van Gog (2006) add that extraneous load does not hamper learning when the instructional task is low in intrinsic load or less complex, but it does hamper learning when the complexity of task or intrinsic load is increased. Hence, reducing extraneous load is imperative for high complexity task.

Apart from intrinsic load which is imposed by the complexity of a to-be-learned content and extraneous load which is imposed by the irrelevant learning activities, there is another cognitive load which is beneficial to schema acquisition and enhances learning. This effective cognitive load is regarded as germane load (Paas, Renkl, Sweller, 2003). Unlike intrinsic load

and like extraneous load, germane load is induced and influenced by instructional design. For example, requiring learner to provide rationale behind worked-out solution steps will be able to induce germane load, provided that learner is capable of providing adequate explanation (Chi et al. 1989).

5   Effectiveness of PBL From the Perspective of Cognitive Load Theory

The use of unresolved problem as stimulus for learning has received a few negative critics. A number of researchers (e.g. Van Gog, Paas, & Merriënboer, 2008) argue that learning by solving problem is not effective for problem solving skill acquisition, especially when learners are in the initial stage of cognitive skill (e.g. knowledge and problem solving skills) acquisition.

At the beginning of cognitive skill acquisition process, learners try to understand the domain knowledge without yet trying to apply it and this is usually dominated by reading and discussion activities (VanLehn, 1996). Novice learners with low prior knowledge lack experience and effective schema, therefore, instruction that consists mainly of problem-solving elements is known to be ineffective for learning because novices always attempt to solve the problem using weak strategies such as means-ends analysis. The use of means-ends analysis in problem solving process will involve learners to interact actively and simultaneously with a number of information such as the problem variables, the solution operators, the goals of the problem, and the relation between these information in working memory. At the same time, they must also figure out some feasible ways to solve the problem. Such strategy might induce high extraneous cognitive load which consume enormous working memory capacity (Renkl, Stark, Gruber, Mandl, 1998). During problem solving process, the student's knowledge about solving that problem will be triggered. Based on information processing system, information from long-term momery will be transferred to working memory for further process. Due to limitation of the working memory capacity, the working memory can easily become overloaded because there are too many information interaction taking place in the working memory when a learner retrieves information related to the problem and interacts that information with the current problem s/he is trying to solve. In such a case, some information might be left out and has to be reaccessed or reactivated. Reactivation of information can only be done effectively provided that there is sufficient working memory. Such high demand of working memory makes the problem solving process more difficult.

In addition, the complex and ill-structured problem used in PBL usually cannot be solved by a simple algorithm and the learners tend to work out the problem through different ways before they come up with the final solution. Such task requires huge working memory resources and leaves insufficient memory space for students to learn new things. Heavy working memory load does not contribute to accumulation of new information in long-term memory due to the congestion of interacting elements and this may not promote learning eventually (Sweller, Van Merriënboer, & Paas, 1998).

6 Conclusion: Is PBL an Ineffective Learning Strategy?

Is PBL an ineffective learning strategy? The answer to this question is simple: NO. In fact PBL is a very effective didactical method if it is applied to the right person and at the right time. Expert learners with profound and well-organised domain knowledge and problem solving schema are the right persons to be exposed to PBL approach. This is because the expert learners can effectively interact with more pieces of information as they are able to integrate those interrelated information as one "chunk" of information. Accordingly, this will reduce the working memory utilisation and as a result, more memory space is available for beneficial cognitive activities, such as organising information and constructing new knowledge. Moreover, due to the fact that expert learners possess more problem solving experiences, they tend to use effective problem solving strategies without burdening working memory resource whenever they are confronted with problem because they are able to recognise the nature of the problem and they tend to generate correct hypotheses more often (Bedard & Chi, 1992). In other words, it is not advisable to apply PBL strategy to novice learners due to their scarcity of domain knowledge and problem solving schema.

Similarly, PBL is arguably not appropriate to be implemented at the initial stage of cognitive skill acquisition. When the novice learners are forced to solve a problem, they tend to use ineffective problem solving methods (e.g. means-end analysis). As previously mentioned, using ineffective problem solving methods may bring about high extraneous cognitive load which will deteriorate learning performance. In short, it is not recommended to apply PBL at the beginning of a lesson or semester because students need to acquire fundamental domain knowledge before we are capable of solving any problem. At the beginning of learning process, it is particularly important to provide guidance and scaffolding to the students.

In order to assist students to acquire domain knowledge and problem solving schema, wroked examples can be used at the starting of the learning process as it does not cause high extraneous cognitive load. Learning with worked examples (example-based learning - EBL) is effective to be implemented together with explanatory activities (e.g. providing explanations by teacher, or generating explanations by students). These explanatory activities not only allow students to comprehend the problem solution procedures, but also enable them to understand the reasons and concepts used behind every solution step. Thus, the students are able to construct new domain knowledge as well as problem solving schemas.

In sum, given that EBL produces positive impact on novice learners who have low prior knowledge, and PBL is fruitful to be applied to experienced learners who possess deep domain knowledge and schema, therefore, it is conjectured that the shortcomings of PBL and can be mitigated by blending both learning strategies. This is to say that the worked-out problem is used at the initial stage of knowledge acquisition or at the beginning of the learning process; whereas the unresolved problem is used at the final phase of the learning process after the students have gained sufficient knowledge.

To date, empirical evidence to prove the efficiency and effectiveness of integrating EBL into PBL is fairly scarce. Clearly, this blended learning approach requires further investigation to examine its impact on student learning performance.

7 References

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