Problem-Based Learning (PBL) as an Assessment Tool in Science Education: A Systematic Review with Exemplars

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Abstract

Problem-Based Learning (PBL) is one of the constructivist teaching and learning strategies that become very popular and used to promote active learning among students in various fields of education. During the implementation of the PBL approach, it could be used as an assessment tool to evaluate students' development of cognitive and affective domains as well as the social skills that need to be pursued by them. The analysis through systematic review in this study revealed that quantitative method is the most popular method used in assessing the implementation of PBL in the primary, secondary and tertiary levels of education. From this study also it was shown that PBL gives a positive impact on the students' development regarding their motivation, attitude, interest, perception and overall achievement. In addition, the implementation of PBL strategies can be associated with other supporting materials (as elaborated in the exemplars given in this study), so that it can assist the teachers to be bold enough to handle the PBL activities in the classroom hence to deliver the knowledge smoothly and in a more meaningful way.

Keywords: Problem-based learning (PBL); Systematic review; Education; Assessment; Inquiry; High school

Introduction

Background and Overview

Problem-based learning (PBL) is one of the teaching strategies that had been widely used in education in the past few decades. The first implementation of PBL was in medical education during the 1960s, where the PBL approach has become more popular in the teaching of physical science programmes. According to Wood (1996), Boud and Feletti (1997), PBL originated from medical science degree courses around the 1960s in North America. The implication was that the strategy is long in existence and PBL was tested in the practical aspect of medical field. In line with this development, Savery and Duffy (1995) reported that suddenly PBL approach became more popular in other regions or continents which involved other disciplinary fields of education. This approach first used in the teaching of chemistry in the early 21st century in the UK Higher Education Institutions (Belt, Evans, McCreedy, Overton, & Summerfield, 2002). This confirmed that the learning strategy is widely accepted as a technique for teaching not only medical science but also educational and social science as well.

Apart from using the PBL as one of the teaching strategies, the instructors need to take into account the modes of assessment used to evaluate PBL problems, designing educational experiences that use the PBL approach (Overton, Byers, & Seery, 2009). When the problems are presented in the PBL setting, it is of greater concern to outline the strategies through which the assessment could be carried out in order to assess whether the targeted objectives are attained or not. Similarly, several aspects need to be considered such as the problem-solving nature of problems provided and the assessment strategies to make sure the delivery of the quality of the final deliverable solution is being achieved (Tai & Chan, 2007). One of the key encouragements for developing learning experiences based on PBL is the development of studies and interpersonal skills but at the same time, both formative and summative assessment strategies have to be constructed to support the development of these skills among students in an attempt to attain the objectives for implementing PBL strategy.

Rationales and Objectives

There are many objectives for implementing PBL approaches. These include the need to update chemistry curricula to meet the requirements of the pre-university educational backgrounds of 21st-century students (Walker & Leary, 2009) and to provide the chemistry graduates with the professional soft skills required in a suitable workplace (Royal Society of Chemistry, 2009). These skills are necessary for the employment opportunity because at the moment industries are only employing graduate with creative mind and skills. Kelly and Finlayson (2007) stated that PBL was identified as an instrument to improvise the training of employability and transferable skills in chemistry degree programmes. The PBL strategy allows the instructors to create learning experiences so that the students can see the connections of learning to their professional development. The practice of PBL tasks require students to take responsibility for the learning process, to be good team players and to develop their interpersonal skills.

Earlier, Raine and Symons (2005), highlighted that PBL problems are usually structured in such a way that students are being given insufficient information so that they need to conduct further research to solve the problems. According to them, the process in the PBL approach promotes social learning by requiring students to collaborate in teams on the development of agreed solutions to problems from all team members. The implication is that 21th-century skills such as communication, critical thinking, collaboration and creativity are expected to be influenced by the PBL. In addition, Kolmos, Xiangyun, Holgaard and Jensen, (2008) and Williams, Iglesias and Barak (2008), PBL contact sessions that consist of the problem-solving process should be facilitated by the teachers or any related professionals. Students will be receiving formative feedback on their problem-solving approach during the contact sessions which indirectly inspire them to reflect on their own skills development as they work collaboratively to solve the problem (Wilkie, 2000). The collaboration may yield better understanding of the problem as each individual would contribute his/her ideas and thoughts The group problem-solving process typically leads to a final summative assessment as revealed by Williams et al. (2010), which is usually assessed by the facilitator or by peer-assessment (Tan & Keat, 2005). The final assessment by the teacher would summatively be presented as the learning outcomes and achievements. The achievements are likely to be better in the case of complex problem-solving compared to the traditional lecture method of teaching.

As Anderson (1998), Darling-Hammond and Synder (2000) cited from Stenberg (1994), the tests implemented in traditional classrooms are not useful tools to measure students' achievement in solving complex problems or open-ended problems. Summative assessment is used as well as a formative assessment technique in the PBL approach (Duch, Groh & Allen 2001; Savin-Baden & Major, 2004). The need to develop authentic assessment approach is important, as PBL is often used to help students to develop skills that may affect their career pathway (Waters & McCracken, 1997; Hanna, 2002; Barber, King, & Buchanan, 2015). These skills enable graduates to solve real life problems and bring about innovations in line with the global changes to satisfy the ever-increasing demand and needs of humans. In view of the above, this research carried out a systematic review on PBL as an assessment tool with exemplars reported.

Problem Statement

Life is always being accompanied by difficulties and challenges. Human beings living in the 21st century need to be effortlessly deal with what many are called as 'terrific problems'. According to Kolko (2011), solving complex problems requires greater collaboration and the linking of different disciplines of knowledge. In addition, problem-solving is the basic human desire that needs to be put into alarm to improve human knowledge in the adaptation to fast-changing global situations (Armstrong, 2012). Solving any type of problem requires some skills to identify the problem and ability to critically as well as creatively think and solve the problem either as individual or in collaboration. These needs and requirement are what called for PBL learning setting.

Barrows and Tamblyn (1980) stated that although PBL was originally used as a formal method in medical schools because of using authentic cases, this approach is being applied even in the universities for various range of disciplines and knowledge areas. Nevertheless, PBL has been further reformed as constructivist approaches to learning in schools as well as universities (Jonassen, Howland, Moore & Marra, 2003). The decision of universities to employ PBL strategy may be as a result of the demand by industries to employ skills-based labour that could innovate new products and services. In this move, PBL has been linked to self-directed outcomes (Biggs & Tang, 2011) and also a collaborative or social learning framework (Wenger, 1998). Hence, students could be grouped to interact socially and make collaboration.

Furthermore, PBL represents the important ingredient in higher-order thinking skills (HOTS) in place of the lower or surface designs of learning as the plain transmission, reproduction or even imitation of content in the form of information or basic skills (Bailey, Hughes & Moore, 2003). Hence, it is expected of questions or problem raised to be of higher order that requires the learners to critically think and respond to the problem. The learners' ability to think and construct meaning to a phenomenon is of great here in this regard. Hmelo-Silver (2004) agreed that PBL which was considered as a model of constructivist learning and knowledge inquiry should be shifted from traditional educational models of exam-based assessment and the teacher-centered pedagogy 'transmission' curriculum to a learner-centred and active process of meaning construction and understanding.

According to Laszlo (1972), Prigogine and Stengers (1984), Mandelbrot and Hudson (2005), this paradigm has comprehended many feedback, appearance, self-organization, and dynamic equilibrium in many fields of education. The outlined features made PBL more or less an assessment based learning strategy. Klein (2006) emphasized how multi-disciplinary collaboration and interdisciplinary problem-solving are more important as this is in line with the earlier work of Mitleton-Kelly (2003) who added how both are a complement to each other rather than feeding content knowledge specialization. In other words, Fauconnier and Turner (2002) agreed that there is a natural connection between systems fundamentals and certainly interdisciplinary to achieve the interdependent requirements of complex problem-solving across all areas of human knowledge.

Research Questions

To this extent, Biggs and Tan (2011) believed that a supporting framework that consists of outcomes-based learning and assessment should be constructed to assist the students to achieve specific learning outcomes. PBL has been particularly discussed in terms of its application and how it is used as the assessment tool during the teaching and learning process. In this paper, the researchers raised the following research questions as guide for study:

- How was PBL used as an assessment tool for different levels of education?
- What are the impacts of the PBL approach towards students' outcomes such as motivation, attitude, achievement, interest, and perception?

Methodology

This study employs systematic review as research method involving the process of selection of literature through various database with evaluation and synthesis of all available evidence. For data collection and analysis, an online database, e-journal and e-books database were used to search for related published articles. Web-based service providers used include ScienceDirect, Springerlink, Web of Science, Scopus, Journal of STEM Education and Google Scholar. Articles obtained were scanned to retrieve the related studies on how PBL was implemented and how it was used as an assessment tool in education.

The following keywords and terms were used: education, assessment, problem-based learning, PBL, teaching and learning, and high school. The researchers further scrutinized the results of the search using the following inclusion criteria: (1) The selected published papers were limited for the last ten years from 2009 until 2019, (2) studies that stated the implementation of investigation related to PBL, the levels of applications and impacts on students' development in cognitive and affective domains. Some of the articles found during the searching phase were not selected as the authors did not mention or explain in detail the impact of PBL implementation in their studies. The papers were analyzed quantitatively and summarized according to the research questions, as presented in Table 1 and Table 2.

Results

How Problem-based Learning (PBL) was used as an assessment tool for different levels of education

Table 1 is the summary of the research studies conducted at the various types of education levels with different methods and instruments used to assess the implementation of PBL as an assessment tool in teaching and learning at various fields all over the globe.

Table 1
Analysis of Method and Instrument Used to Assess the PBL Approach

Authors	**Educational Level**	**Method**	**Instrument**
Williams (2016)	Tertiary	QT	• Questionnaire • Peer-review survey • Peer-review process in a presentation
Ananda and Azizah (2016)	Secondary	QT	• Questionnaires • Tests • 4D development procedure.
Gorghiu, Drăghicescu, Cristea, Petrescu and Gorghiu (2015)	Secondary	QT	• Assessment • Questionnaire of the Module -MoLE
Amoako-Sakyi and Amonoo-Kuofi (2015)	Tertiary	QT	• PBL tutorials and seminars; • Practical sessions • Structured clinical skills training; lectures; and community fieldwork.
Surif, Ibrahim and Dalim (2014)	Tertiary	QT	• Paper-and-pencil test
Tosun and Yasar (2013)	Primary Secondary Tertiary	QT	• Questionnaire • Achievement test • Interview and alternative data collection tool
Tarhan and Acar-Sesen (2013)	Secondary	QT	• Prerequisite Knowledge Test • Post-Test • 5-point Likert type PBL • Interviews with students who have experience in PBL
Gallagher and Gallagher (2013)	Secondary	QT	• Achievement test scores • Teacher ratings of students' engagement in PBL • Independent ratings of students' performance on specific PBL assignments.
Judge, Osman and Yassin (2011)	Tertiary	QT	• Post-test • PBL integrated with ICT module • PBL module • Four PBL cases
Zulkifli (2016)	Secondary	QT	• Pre-test • Post-test • Questionnaire
Ng, Fong and Soon (2010)	Secondary	Mixed	• Pre-test (Fluid Intelligence Test or FIT) • Post-test (FIT) • PBL via Scaffolded Instruction (PBL-SI)
Kim, Belland and Walker (2018)	Tertiary	QT	• Computer-based scaffolding with PBL activities
James Long and Bae (2018)	Primary	QL	• Interviews • Lesson observation

Ince (2018)	Secondary Tertiary	QT	• Pre-test • Post-test • Contextually rich problem • Open-ended questions • Interview after using metacognitive problem solving
Wijnen, Loyens, Smeets, Kroeze and van der Molen (2017)	Tertiary	QT	• Self-study strategies and activities using PBL • Interviews
Wang, Samaka, Miao, Ali and Hoppe (2016)	Secondary Tertiary	QT	• Web-based PBL application • Combined a model-driven approach with semi-structured data management
Mubuuke, Louw, and Van Schalkwyk (2016)	Tertiary	QL	• Individual interviews • Group discussions were • Writing of field notes.
Dolmans, Loyens, Marcq and Gijbels (2016)	Tertiary	QL	• A systematic review of the literature of PBL implementation
Richards (2015)	Secondary Tertiary	QL	• A systems model of complex problem solving to help students' problem-solving skills
Sitti, Sopeerak, and Sompong (2013)	Tertiary	Mixed	• Instructional model based on connectivism learning theory • Develop, utilize, and evaluate the instructional model-based
Suwono and Kumala (2019)	Secondary	QT	• Problem-Based Learning and Online Instructions
Salinitri, Lobkovich, Crabtree and Wilhelm (2019)	Secondary	QT	• Problem-Based Learning and Students' Performance

Abbreviations

QT	Quantitative Method
QL	Qualitative Method
MIXED	Mixed-Method, i.e. A Combination of Quantitative Method and Qualitative Method

Impact of the PBL Approach towards Students' Outcomes

The following Table 2 summarizes the findings on the impacts of the implementation of PBL in education towards students' development of cognitive and affective domains in terms of motivation, interest, achievement, attitude and perception.

Table 2
Analysis of Impacts of Implementation of PBL Approach towards Students' Development

Authors	Motivation	Attitude	Achievement	Interest	Perception
Williams (2016)	/	/		/	/
Ananda and Azizah (2016)	/	/	/		
Gorghiu, Drăghicescu, Cristea, Petrescu and Gorghiu (2015)	/	/	/		
Amoako-Sakyi and Amonoo-Kuofi (2015)					/
Surif, Ibrahim and Dalim (2014)			/		
Tosun and Yasar(2013)		/	/		/
Tarhan and Acar-Sesen (2013)	/	/	/	/	/
Gallagher and Gallagher (2013)	/	/	/	/	/
Judge, Osman and Yassin (2011)		/			
Ng, Soon and Fong (2010)	/	/	/	/	/
Zulkifli (2016)	/	/	/	/	
Kim, Belland and Walker (2018)	/	/	/	/	
James Long and Bae (2018)	/	/		/	
Ince (2018)	/	/	/		
Wijnen, Loyens, Smeets, Kroeze and van der Molen (2017)	/	/	/		
Wang, Samaka, Miao, Ali and Hoppe (2016)	/	/			/
Mubuuke, Louw, and Van Schalkwyk (2016)	/	/	/		/
Dolmans, Loyens, Marcq and Gijbels (2016)	/	/			/
Richards (2015)	/	/	/		
Sitti, Sopeerak and Sompong (2013)	/	/	/		
Suwono and Kumala (2019)	/		/		
Salinitri, Lobkovich, Crabtree and Wilhelm (2019)			/		

Discussion

The main aim of this paper was to obtain information about the implementation of PBL in education as well as its impacts on the students' development and how PBL is being used as an assessment tool with exemplars reported. However, the discussion of the results was done based on the research questions and variables in Tables 1 and 2.

Educational Level and Implementation of Problem-Based Learning

From the summary in Table 1 as also indicated in Figure 1, fourteen studies were carried out at the tertiary level, only two in the primary level and eleven focused on the secondary level. The results show that most of the studies were carried out at the secondary and tertiary level of education. The findings revealed that higher-order thinking skills are much needed by the students following their level of cognitive development to solve complex problems that can be applied to face real-life problems while in primary school mostly the activities and problems to be solved are of low level thinking order skills based on their maturity nature.

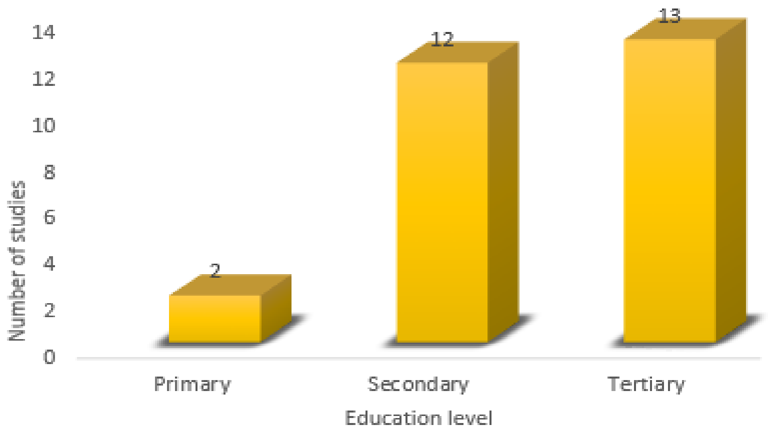

Figure 1. Level of education and Problem-Based Learning.

Research Approaches and Problem-Based Learning

According to Table 1, most of the researchers used a quantitative method to assess the implementation of PBL in various fields of education. It is shown in Figure 2 that sixteen of the studies representing 73% were used quantitative method, followed by a qualitative method in four studies with a percentage of 19% and only two studies representing 5% employed mixed-method. From the result, it could be gathered that researchers were more favored in doing quantitative methods compare to the qualitative method. This may be due to the notion that the researchers were capable of studying the PBL without influencing it or being influenced by it because the research approaches and PBL are independent entities. On top of that, the sample sizes are much bigger than the qualitative method so that the statistical methods can be used to ensure that samples are representative of a larger group (Carey & Smith, 1993).

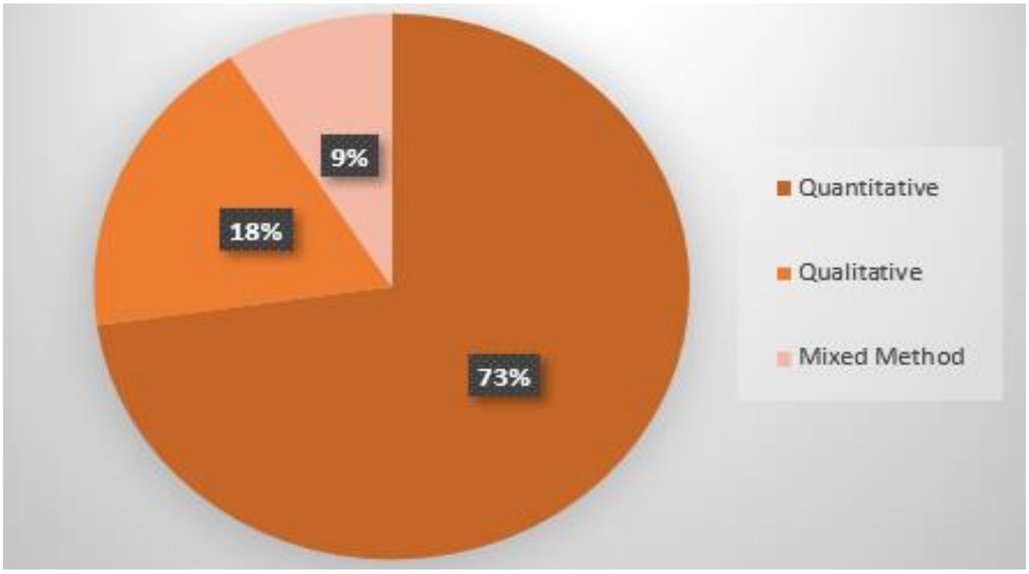

Figure 2. Research approaches and Problem-Based Learning.

In contrast, the qualitative method involves multiple realities or truths based on one's construction of reality. According to Altheide and Johnson (1994), the qualitative method is based in interpretivism and constructivism (Guba & Lincoln, 1994). In addition, the researcher and the focus of study which is PBL are interactively linked to each other, hence the findings are mutually created with the context of PBL being studied. The sample sizes are relatively small, including in-depth and focus group interviews. Even though the sample is small and cannot represent a larger group, important information could be provided by purposeful samples.

However, two of the studies reviewed systematically (as summarized in Table 1) were conducted using a mixed-research methods because both methods can be done if the researcher believed the objective of the research can be achieved by applying these methods. According to Haase and Myers (1988), if the goal of understanding the world we are living is the same for both methods, then the combination of both methods is applicable. Furthermore, they are sharing the same objectives and commitment along the research process of PBL in education.

Learning Outcomes and Problem-Based Learning

Table 2 shows the effects of the implementation of PBL in education towards students' development of cognitive and affective domains according to research question number two. It is shown that 18 out of 22 studies show the positive impact on the attitude, followed by motivation for 17 studies, an achievement for 16 studies, perception for 9 studies, and lastly 7 studies for interest as indicated in Figure 3. In addition, the students' interest and perception also improved after being involved with problem-based learning (PBL) activities.

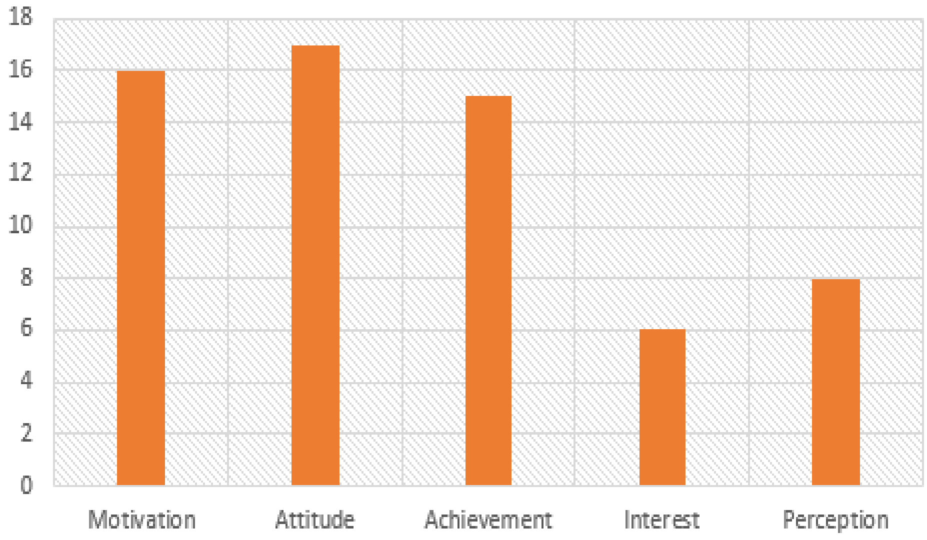

Figure 3. Learning outcomes and Problem-Based Learning.

PBL as an Assessment Tool with Exemplars Elaborated

The implementation of PBL is always supported by many ideas in terms of instrument or model to enhance the problem-solving skills among the students. All students agreed that the worksheet of language-oriented PBL helped them to solve problems as it is easily understood in the studies conducted by Ananda and Azizah (2016). In addition, the use of the symbol or icon on each worksheet oriented PBL should be consistent to allow the students to know what is discussed in each question. On top of that, student's confidence levels in all skills are generally good and most of the students responded as confident or very confident for both terms 'Teamwork' and 'Problem-solving Skills'.

It cannot be denied that the quality of communication between teachers and students plays a huge role in implementing PBL activities in the classroom. Teachers need to be aware of the feedback received from the students, in order to control the smooth delivery of knowledge (Gorghiu, Drăghicescu, Cristea, Petrescu & Gorghiu, 2015). From this point, teachers could drive two benefits: 1) PBL as a learning strategy and 2) PBL as an assessment tool. PBL is learning strategy that involves real-world problem solving which enable students think critically and acquire skills to solve the problem presented. Indirectly it will give positive impacts on students' development while solving the problems. Furthermore, the teachers should be prepared while handling PBL activities so that the knowledge can be delivered successfully and assessment could be made at the same time. These may lead the researchers to draw the attention of teachers on the quality of the communication with students for example during Science lessons and beyond. The students should be approached as a teacher's partner in training. During the activities, the students who act as active participants heavily involved in this process which can lead to the development of a broad range of learning and problem-solving skills, as well as communication and collaboration among peers.

Furthermore, PBL activities should provide the problems that have more than one answer such as open-ended questions. According to Cracolice, Deming, and Ehlert (2008), most of the students will only develop their explanation skills if they are required to do so. Open-ended questions are rarely tested and complex problems usually involving open-ended questions for the students to solve. Students face difficulties in answering questions and solving an open-ended problem because it is beyond their abilities and also because of the lack of the skills needed (Chin & Osborne, 2008). Their explanation skills are not sufficiently developed to allow them to successfully solve open-ended problems. According to Reid and Yang (2002), real-life problems are always related to open-ended problems which can indirectly enhance a student's problem-solving skills. These skills are not only fundamental but also practical in life and can be used directly in their lives outside of the classroom. Based on the qualitative studies conducted in Singapore by James Long and Bae (2018), lack of assessment, resources and time to plan the PBL activities affect the implementation of this approach. Hence there is an indication that apart from the resources and time frame, one of the key important components in PBL setting is how the problem of critical questions are being planned to be presented also whether they could be used to assess the overall learning.

In addition, PBL which is known as an active learning approach that follows the constructivist approach has positive effects on learning achievement, overcoming alternative conceptions, and developing some social skills. Therefore, it is suggested that instructional methods promoting high-level cognitive processing such as PBL should be integrated into the science curriculum from primary, secondary and up to the undergraduate level. From the results reported by Tarhan and Acar-Sesen (2013), students could be achieving the skills that they need to be successful in their life if PBL is widely used in science classes. Such studies should be continued and PBL activities should be developed as well as validated for other science fields too. Thus, cognitive learning skills, social skills, and cooperative working skills can be developed.

From a research conducted on third-year students in the higher institution (Judge, Osman, & Yassin, 2011), PBL was implemented by using the Communication Systems II Module. Based on the staff's observation, students enhanced their communication skills by engaging in the

PBL process. Previously the course was taught using the lecture method. By switching to PBL, students were required to form groups and solve the problems given by their tutors. The success of the group process depends on small decision making, which in turn is influenced by communication skills and interpersonal skills of group members (Uden & Beaumont 2006). Overall students developed their communication skills while undergoing the PBL process. At a later time, Kim, Belland and Walker (2018) revealed that PBL requires students' different abilities such as problem-solving skills, information-searching strategy, creative thinking, and collaborative learning skills. Hence, self-callscaffolding should be considered as an effective strategy for promoting strong learning outcomes. In addition, when scaffolding customization occurs among students themselves, its effects may be best because self-selected scaffolding can improve students' self-directed learning and motivation toward their learning. The study on the use of PBL integrating technology-enhanced scaffolded instruction as reported by Ng, Soon and Fong (2010) also found to have enhanced motivation among moderate secondary science learners.

In another narration by Ince (2018), teaching has generally focused on problem-solving behaviours according to those who are "experts and novices". According to this classification, the Expert Problem Solver can use problem-solving strategies to solve the problems efficiently compare to those classified as Novice Problem Solver. Studies have revealed that Expert Problem Solver solves the problems step-by-step from understanding the problem, determining the concepts, making the plan, solving the problem, and evaluating the outcome. Unfortunately, Novice Problem Solver tends to solve problems by first using mathematical expressions. It was stated that a students' success in solving the physics problems depends not only on the student's knowing the concepts but also their ability to interlink all the information and concepts in the problem. Wijnen, Loyens, Smeets, Kroeze and van der Molen (2017), in their findings showed that "PBL students" reported to apply deep processing, self-regulation, and external regulation more frequently than their "non-PBL counterparts" which is also revealed by most of the articles analyzed by this study. Therefore, PBL seems to contribute to the use of effective learning strategies, even though "PBL students" also relied more often on external sources for their regulation, such as teachers, course material, and assessment.

Conclusion

Implications and Limitations

From the studies of PBL implementation in various kinds of educational backgrounds, it seems that PBL is a teaching strategy which is suitable to be conducted in the primary, secondary and tertiary level of education. However, at the primary level, simple problem needs to be given to students which would correspond to their level of cognitive development. Perhaps it follows the constructivist way of teaching which can be a success if it is integrated with many other tools or instruments. Implementation of PBL in the classroom may not be easy as the teacher must know the role of the students, the phase and process of activities to take place, framing the problems and presenting them as an assessment tool as well as the outcomes from the execution of the process to be achieved during the lesson of the day.

PBL approach can be beneficial to the students' development in terms of cognitive learning skills and social skills. With the properly structured PBL activities during the learning process, students will be able to improve their communication while collaborating among peers to solve even complex problems related to real-life problems. However, there are some constraints that affect the implementation of the PBL approach. In addition, many tools and instruments need to be developed to assist the teachers in implementing the process of the PBL during teaching and learning in the classroom.

Significance and Future Direction

The use of most relevant tools and instruments can be beneficial to provide the learning process in a meaningful way while conducting the PBL activities as a medium of assessment as reported by Ng, Soon and Fong (2010). Some of the websites related to PBL that had been developed is undeniably helpful. For example, (i) *www.udel.edu/pbl; (ii) www.imsa.edu/team/cpbl/cpbl.html; (iii) http://pbli.org and (iv) www.mcli.dist.maricopa.edu/pbl/info.html* are some of the PBL useful websites that are found interesting *etc* (Encyclopaedia, 2020). It is important for the teachers to cater to any feedback from the students and assess the students' cognitive as well as other soft skills at the same time.

Lastly, further research that reveals many factors may inspire the teachers to administer the PBL during their teaching and learning process in the future such as problem structure of the PBL activities. Studies on how facilitators support the development of greater levels of confidence in discipline-specific skills such as experimental design and the scientific method is of immense importance are also recommended.

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