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Effectiveness of Problem-Based Learning to Students' Problem-solving and Critical Thinking Skills: A Systematic Review

Gabrielito D. Garil[1*] and Ryan V. Dio[1*]

[1]**Sorsogon State University, Philippines**

RESEARCH ARTICLE

Abstract

The effectiveness of PBL in various fields has been explored for the past decades – in medical schools, higher education schools, and even in K-12 schools. However, its effectiveness relative to students' problem-solving and critical thinking skills remains narrow, mainly in K-12 secondary schools. Moreover, only a few studies have focused on this concern over the last decade. Therefore, this systematic review aims to study the effectiveness of PBL alone and against the conventional model in relation to the problem-solving and critical thinking skills of students in secondary school. The study utilized the PICO (Population, Intervention, Comparison, Outcome) Concept to frame the research questions, followed the seven stages of the Systematic Approach, and employed the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) Protocol in selecting and analyzing the ten primary resources generated from online databases such as Google Scholar and Semantic Scholar. The resources showed similar quantitative methodology in investigating the effectiveness of PBL at such a level of education. Overall, the analysis shows that 100% of the studies indicated that PBL significantly impacts the students' problem-solving and critical-thinking skills and should be applied in teaching and learning. Furthermore, it is recommended that an extensive, similar study be conducted and possibly include more academic resources to investigate this learning model's true effectiveness further.

Keywords: PBL, Problem-based Learning, Problem-solving Skills, Critical Thinking Skills

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1 INTRODUCTION

While modern education is continuously evolving and various teaching and learning practices are emerging, cultivating essential mathematical skills, such as problem-solving and critical thinking, has become a vital goal for educators and policymakers alike. These skills are very prominent and can be mastered by the students. They are considered cornerstones in preparing students to confront the challenges of the ever-evolving world and succeed in their personal and professional lives.

For years, educators have been investigating which teaching and learning method will best suit the varying needs of their learners. The most common is the conventional method, a teacher-directed approach to learning where students sit and listen (Tularam, 2018). This method only involves direct instruction by the teacher, whose sole role is to transfer knowledge to the learners and conduct assessments afterward (Abah, 2020). However, this typical method

has been proven by many studies to be disadvantageous and ineffective in enhancing learning and, more specifically, developing metacognitive skills (Yunawati, such as critical thinking and problem-solving skills. However, as this conventional method may sometimes fall short in fostering these skills, alternatives, such as Problem-Based Learning (PBL), have gained significant attention for their potential to enhance these skills.

PBL is an instructional method in which students learn through facilitated problem-solving (Hmelo-Silver, 2004). In contrast to the conventional teaching method, in PBL, the students are the core of the teaching and learning process. They work in small groups collaboratively to determine the requirements to solve an authentic problem relevant to their lives. By immersing students in real-world problem scenarios, PBL aims to develop their mathematical problem-solving skills . Through the implementation of this method, PBL positively impacts their critical thinking skills (Kamil & Velina, 2019).

Numerous studies have explored the efficacy of PBL in various fields, including in a medical school at McMasters University in Canada, where PBL was generally first developed and implemented (Servant-Miklos, 2018) and has been implemented in numerous higher education institutions and even some K-12 schools. Since its development, it has expanded and was further studied by many researchers, proving its potential, usefulness, effectiveness, and advantages against alternative methods.

Encompassed in this review is the general objective of this study, which is to explore the various impacts or contributions of PBL to the problem-solving and critical thinking skills of high school students.

1.1 Problem-Based Learning (PBL)

As stated previously, Hmelo-Silver (2004) defined PBL as an instructional method in which students learn through facilitated problem-solving. The very core of this method is that the students are the center of the learning process, guided by a tutor who facilitates and helps the students structure their learning. In addition, in PBL, students learn content, strategies, and self-directed learning skills through collaboratively solving problems, reflecting on their experiences, and engaging in self-directed inquiry. Thus, these made PBL one of the most influential revolutions and promising paradigms in education that encouraged many institutions to implement it.

PBL may appear almost recognizable to everyone since its procedures and theories are associated with John Dewey's progressivism philosophy. In his early philosophical focus, he suggested that learners are not passive recipients of knowledge but need to be involved in their learning using their experiences as a starting point (Savery, 2006).

Furthermore, Anazifa (2016) cited in his study the five operational steps from PBL: (1) giving orientation about the problem that the student will discuss, (2) organizing students to do research, (3) helping students to investigate the problem, (4) developing and exhibiting the artifact, and (5) analyzing and evaluating problem-solving process. These steps in PBL provided a framework for researchers as to how this learning model should be implemented.

1.2 Problem-Solving and Critical Thinking Skills

Many authors have defined problem-solving skills, and one of the very first was Polya, who defined problem-solving as finding a way around a difficulty, around an obstacle, and finding a solution to an unknown problem. Similarly, critical thinking is systematic thinking that develops logical and critical thinking on mathematical problems (Syafril et al., 2020).

Developing these two competencies or skills may burden some teachers in an actual classroom setting because it may require several procedures and preparations. However, this is how PBL will play its vital role. PBL has several advantages as one of the teaching and learning models. The studies included in this review provide an overview of its effectiveness in enhancing these skills. Though the results of the individual studies may not guarantee reliable results, their outcomes

were promising in terms of whether PBL significantly impacts the students' problem-solving and critical-thinking skills.

Additionally, PBL impacts focusing on secondary schools, particularly on students' Mathematical problem-solving and critical thinking skills in the past decade, remain relatively narrow. Therefore, this review aims to bridge this knowledge gap by thoroughly analyzing the previous studies and literature related to the impacts of PBL on mathematical problem-solving and critical-thinking skills. This review will examine selected studies encompassing various grade levels on the secondary level and methodologies that will suit this review.

2 METHODOLOGY

This review employs a structured and standard procedure to ensure an accurate outcome. The selection of relevant studies involves the utilization of genuine databases, such as Google Scholar and Semantic Scholar. The guidelines recommended by Giorgia (2021) were implemented specifically for this study.

Figure 1. A Systematic Approach: The Seven Stages

2.1 Identify the Research Question

To construct the research question for this study, the researcher referred to the concepts of PICO [Patient or Population, Intervention, Comparison (if there is any), Outcomes] to develop a researchable question. The PICO framework is used extensively in the compilation of systematic reviews as the means of framing research questions Scells et al. (2017).

The researchers then conducted preliminary searches online from the databases to initially select relevant resources relating to the impacts of PBL on students' problem-solving and critical-thinking skills. The researchers found that there were reasonably sufficient resources related to the matter, and therefore, the research questions that were formulated are the following:

A) Does problem-based learning (PBL) significantly impact high school students' mathematical problem-solving and critical thinking skills?

B) Compared to conventional learning methods, have high school students' mathematics problem-solving and critical thinking skills substantially improved under the PBL approach?

Table 1 shows the construction of the research question guided by the PICO concept.

Table 1. PICO Concept (Framing of Research Questions)

	P (Patient, Population)	I (Intervention)	C (Comparison)	O (Outcome)
A	High School Students	Problem-Based Learning Approach	Conventional Methods of Learning	Enhanced Mathematical Problem-Solving and Critical Thinking Skills
B	High School Students	Problem-Based Learning Approach		Enhanced Mathematical Problem-Solving and Critical Thinking Skills

2.2 Define the Inclusion and Exclusion Criteria

This systematic review followed the PRISMA Protocol (Preferred Reporting Items for Systematic Review and Meta-Analysis Protocol). The PRISMA 2020 statement provides updated reporting guidance for systematic reviews that reflect advances in methods to identify, select, appraise, and synthesize studies (Page et al., 2021). Thus, This protocol aided the researcher in gathering related research results in quantitative graduate studies (Figure 2).

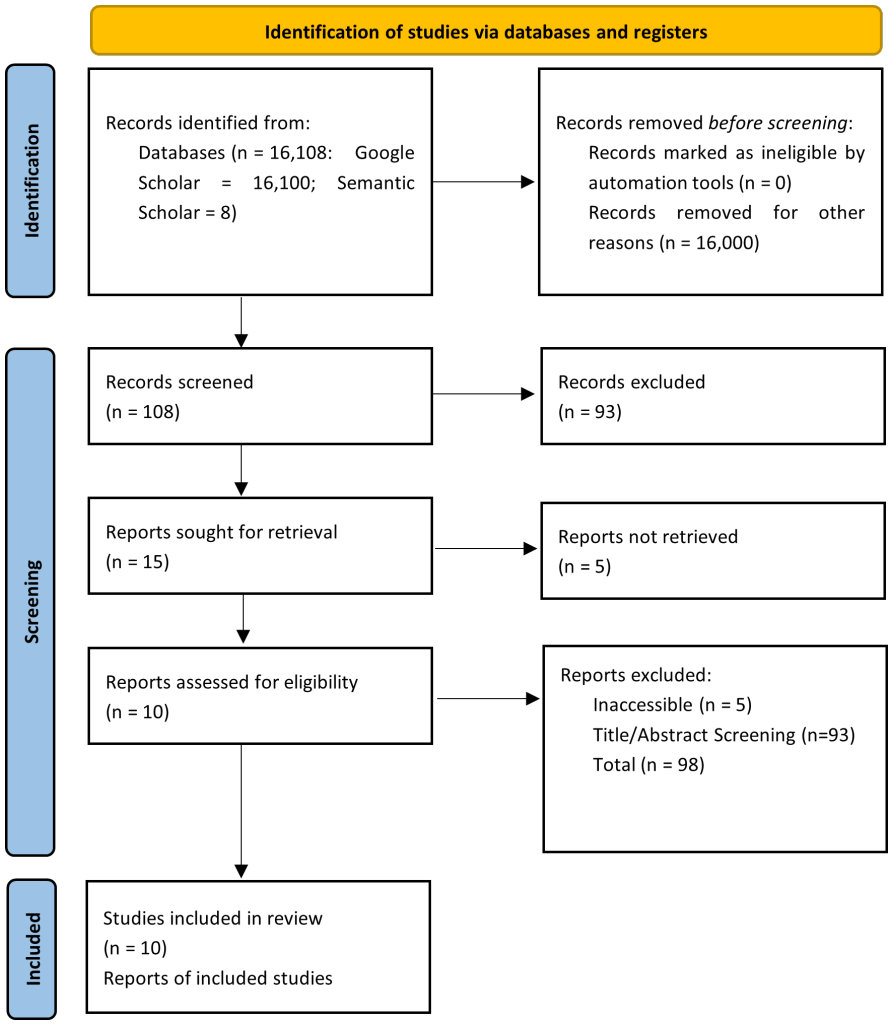

Figure 2. PRISMA Protocol Phase (Selection of Studies)

However, the researcher ensured the authenticity and relevance of the gathered materials by adapting the Inclusion and Exclusion criteria (McKenzie et al., 2019). Thus, the selected resources should have met the following Inclusion criteria:

a. Published between 2010-2022.
b. Materials tagged with 'Open-access' or 'full-text available.'
c. Studied the implementation and effectiveness of PBL.
d. Implemented PBL as a teaching method in mathematics education.
e. Implemented PBL in secondary school.
f. Evaluated the PBL's efficacy in enhancing students' problem-solving and critical-thinking skills.

Conversely, the Exclusion criteria disregard studies that were irrelevant to this review. The following criteria were observed:

a. The materials are not published between 2010-2022.
b. The studies did not implement and assess PBL.
c. PBL not implemented in mathematics education.
d. PBL did not evaluate the effectiveness of PBL in enhancing students' problem-solving and critical-thinking skills.
e. PBL not implemented in secondary school.
f. "Unavailable" or "inaccessible" materials.

Six (6) criteria for inclusion and exclusion were employed in this study from the preliminary stage up to the final stage of classifying and identifying relevant studies. These criteria were significant in narrowing the scope and ensuring the validity of this review.

2.3 Search for Studies

During the preliminary stage, the researcher conducted an initial search with keywords like "PBL in mathematics education," "Problem-based learning approach," "Implementation of Problem-based learning," and "Effectiveness of PBL." Google Scholar and Semantic Scholar were used as the primary database for searching relevant materials online. Upon considering the results generated by the databases, and for the researcher to narrow down the scope of this review, search keywords and terms like "PBL implementation in high school," "Impacts of PBL in high school students," "effectiveness of PBL in enhancing problem-solving skills and critical thinking skills" were included.

Additionally, Google Scholar advanced search that was also administered to get precise results is as follows:

1. With all of the words: problem-based learning
2. With at least one of the words: PBL, problem-based learning, problem-solving skills, critical thinking skills
3. Where my words occur: "in the title of the article," "anywhere in the article."

2.4 Selection of Studies

The researcher underwent a manual screening of the resources. Following the phases of the PRISMA Protocol, during the identification phase, 16,108 resources were collected from the primary databases: Google Scholar n = 16,100; Semantic Scholar n = 8. The researcher then removed resources with a total of 16,000 that were considered to be excessive and extraneous.

In the screening phase, 108 resources were screened, and 93 were excluded after reviewing the content of each resource's title and abstract. To guarantee that the resources gathered are eligible for this study, the Title and the Abstract must be congruent with the objective, abide by the inclusion criteria, and answer the research questions. Merely 15 resources were left for the retrieval stage. Five (5) of them were then excluded because they were "inaccessible" and had no "full text" available. Ten (10) resources were considered eligible for this review at the final screening stage. Ten relevant primary studies were included after undergoing a series of phases.

2.5 Extraction of Data

The data from the primary studies that went through the screening and met the criteria were extracted. Data characteristics such as the author (reference), publication year, research methodology, education setting used for implementing the PBL, and research outcomes were a few of the necessary information for this specific review. The researcher manually performed the extraction himself with no coding or automation tools. Moreover, the extracted data, as shown in Table 2, provides the characteristics of the data extracted from the ten resources and, most importantly, provides an answer to the first sub-question of this review.

Table 2. Characteristics of the Resources I

Code	Author	Publication Year	Research Design	Education Level	Sample Size	Research Outcome/ Objective
R01	Arifin et al. (2020)	2020	Quasi-Experimental	SHS	199	Develop student Critical Thinking Skills [and retention in mathematics] through PBL models
R02	Dharma et al. (2020)	2020	Quasi-Experimental	SHS	56	Effect of Problem Based Learning (PBL) on learning outcomes through critical thinking.
R03	Dorimana et al. (2022)	2021	Quasi-Experimental	SHS	54	Investigated how the problem-based learning model could enhance learners' problem-solving abilities in mathematics
R04	Eviyanti et al. (2017)	2017	Experimental Research	JHS	55	Determined the increase in the mathematical problem-solving ability of Students are taught using a problem-based learning model that is against conventional teaching.
R05	Hendriana et al. (2018)	2018	Pre-test-Post-test Experimental Research	JHS	66	Analyze the role of problem-based learning on students' mathematical problem-solving ability [and self-confidence]

R06	Khoiriyah and Husamah (2018)	2018	Class Action Research	JHS	31	Improve students' [creative thinking skills], problem-solving skills, [and learning outcomes] through PBL.
R07	Lapuz and Fulgencio (2020)	2020	Experimental Research	JHS	27	PBL improved the critical thinking skills of the students
R08	Sholihah and Lastariwati (2020)	2019	Class Action Research	JHS	25	PBL model improved one of the 21st-century competencies, namely critical thinking and problem-solving
R09	Widyatiningtyas et al. (2015)	2015	Post-test only Experimental Research	SHS	140	Analyze the influence of problem-based learning approach [...] on student's mathematics critical thinking ability.
R10	Yolanda (2019)	2019	Quasi-Experimental	JHS	74	Studied the effectiveness of problem-based learning on mathematical critical thinking skills of junior high school students.

Table 3 provides a more condensed distribution and presentation of the studies' characteristics about the predetermined criteria.

Table 3. Characteristics of the Resources II

No	Criteria	Target Mathematical Competence			Comparating	Non-Comparating
		Critical Thinking Skills	Problem-Solving Skills	Both		
Number of studies	-	-	-	-	6	4
Publication date	2010-2012	0	0	0		
	2013-2015	1	0	0		
	2016-2018	0	3	0		
	2019-2022	4	1	1		
Study level	SHS	1	3			
	JHS	2	3	1		
Duration of meetings	3-5		1			
	>5		2	1		
	unspecified	4	2			
Sample size	<30	1		1		
	30	5	3			

Based on the table, in 12 years, studies involving improving problem-solving skills under PBL implementation were slightly dominant compared to studies focusing on critical thinking. Similarly,

only a single study was found to target both competencies. It was also emphasized that six studies have comparators (PBL against Conventional learning), and 4 have non-comparators. These four studies mainly employed a one-group experimental or class action research, requiring a single group as the subject where PBL would be implemented. Hence, it will be a challenge for future research to conduct more studies specifying the effectiveness of problem-based learning in enhancing the two skills of high school students.

2.6 Assessing of Quality

The quality of the selected primary studies is vital for this systematic review to prevent any biases. During the data extraction, the studies' validity was emphasized as it may affect the results of this review. Specifically, apart from referring to the inclusion and exclusion criteria, the effect sizes were also calculated because few of the sample sizes were relatively small, which would lessen the validity of the primary studies. Also, effect size is especially important because it allows us to compare the magnitude of experimental treatments from one experiment to another (Thalheimer & Cook, 2009). An effect size classification, was used to determine whether the selected studies have practical significance.

A value between -0.15 and 0.15 suggests that the effects are negligible or can be ignored, 0.16 to 0.40 is low, 0.41 to 0.75 is medium, 0.76 to 1.10 is high, 1.11 to 1.45 is very high, and a value greater than 1.45 suggests an excellent effect size. The larger the effect size, the more likely the studies have real-world significance.

Table 4. Effect Size of the Studies

Code	n	ES	Interpretation
R01	199	1.64	Excellent
R02	56	0.78	High
R03	54	0.56	Medium
R04	55	0.99	High
R05	66	0.60	Medium
R06	31	-	-
R07	27	2.09	Excellent
R08	25	-	-
R09	140	-	-
R10	74	0.76	High
Weighted Mean		**0.94**	**High**

The weighted average effect size, as shown Table 4 above, is 0.94, implying a "High" practical significance. However, the effect sizes of three out of the ten studies were not determined due to the lack of statistical data, such as the standard deviation. It is understood that this may affect the validity of the three studies and the entirety of this review. However, 10 or 100% of the studies provide one of the necessary data, the obtained mean which interpretation can be patterned.

3 RESULTS AND DISCUSSIONS

The data from each primary resource, particularly the statistical analysis, were extracted to provide complete overviews of the methodologies or statistical treatments applied. Ten (100%) resources had the necessary statistical data to answer the research questions and draw meaningful conclusions.

3.1 Review of Statistical Analysis

Table 5 shows the statistical data extracted from each study to provide evidence of the findings relevant to the impact of PBL in general and in contrast to conventional learning.

Table 5. Result of Statistical Data Extraction

	Statistical Data									
	PBL					Conventional Method				
	Mean			SD		Mean			SD	
Studies	Pre	Post	n	Pre	Post	Pre	Post	n	Pre	Post
R01	55.87	82.28	97	16.41	5.34	53.85	77.69	102	16.11	5.75
R02	74.2	77.43	28			67.05	69.57	28		
R03	22.11	37.30	54	6.12	8.77	-	-	-	-	-
R04	43.75	85.71	28			41.70	71.48	27		
R05	14.48	35.52	33	15	6.59	14.21	31.03	33	4.48	4.95
R06	78.78	99.75	31			-	-	-	-	-
R07	9.52	19.69	27	2.47	3.78	-	-	-	-	-
R08	70.4	86.4	25			-	-	-	-	-
R09	37.7	32.57	70			-	-	70	-	-
R10	7.43	42.16	37	6.934	13.720	6.76	35.27	37	5.678	11.899
	54.32	78.75				40.59	62.09			
Weighted Mean	**41.26***	**56.92***				-*	-*			

** - without comparator [class action research, one-group experimental research]*

3.2 Significant Impacts on the Problem-Solving and Critical Thinking Skills

Also in Table 4 shows the statistical detail in accord with the impacts of PBL on problem-solving, critical thinking, and both skills. Implementing PBL produced adequate evidence that it positively impacts students' problem-solving and critical-thinking skills. The mean obtained from the post-test conducted from each study was significantly higher than that of the pre-test. Hence, a greater result in the post-test indicates a significant change that corroborates the effectiveness of PBL in improving the learners' learning experiences, problem-solving skills, and critical thinking skills.

3.3 Conventional Methods versus PBL

It is understood that the student's performance before the interventions was both low and comparable. However, based on the six studies included in this review, it was determined that PBL had outdone the Conventional Learning model in improving students' skills. Each study, apart from R09, signifies that the PBL has a bearing on the post-test result with a weighted mean of 78.75 against the 62.09 of the Conventional method. Similarly, the four remaining studies without a comparator, with the weighted mean of 56.92 and 41.26 for the post-test and pre-test, respectively, indicate a substantial change in the result after the intervention was implemented.

4 CONCLUSION AND RECOMMENDATIONS

According to the result of the analysis, it is evident that PBL provides students with a new approach to learning. PBL has become excellent in developing the problem-solving and critical thinking skills of both junior high school and senior high school students. Also, according to the data of the selected primary studies, PBL has positively impacted the development of the skills above compared to the implemented conventional learning models.

PBL has been implemented for decades; however, recent studies remain limited, so further investigation and study of this method are highly required. The strong point of this systematic review was that it studied PBL's impacts on problem-solving and critical-thinking skills, which was presumed to be one of the goals of PBL (Hmelo-Silver, 2004). It is also vitally important

that current generations of students experience PBL and engage in constructive solution-seeking activities (Savery, 2006) to develop these important skills. Additionally, Hmelo-Silver (2004) stated that as students become more experienced with PBL, facilitators can fade their scaffolding until, finally, the learners adopt much of their questioning role. Additionally, curriculum developers should design a curriculum that integrates and implements this method, considering that it has improved the learning experiences and enhanced the learners' mathematical skills. Overall, this study implies that PBL is an important learning model that helps students perform better in several subjects and skills, i.e., critical thinking and problem-solving (Faqiroh, 2020). Thus, this learning model should be implemented by secondary schools and applied in the learning process following the problem-based learning steps.

For further study or review focusing on the implementation and impacts of PBL, this systematic review suggests that the researchers should broaden the selected primary resources and include more databases. Also, the researcher shall select primary resources where the characteristics, such as statistical data, are presented and meet the specified criteria. Therefore, more similar academic reviews are highly recommended for future researchers.

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