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THE IMPACT OF PROBLEM-BASED LEARNING TOWARD ENHANCING MATHEMATICAL THINKING: A META-ANALYSIS STUDY

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Abstract

This study aims to analyse the application of Problem Based Learning (PBL) in improving problem solving skills, literacy, communication, critical thinking, and creative thinking in mathematics. This study used a meta-analysis method by analysing 114 primary studies that met the inclusion criteria. Search data using online databases such as ERIC and Google Scholar, Comprehensive Meta-Analysis (CMA) program as analysis tools. The results of the study found that the PBL effect size of the total experimental results was generally categorized as having a large effect on the quality of improving mathematical thinking. The moderator variables considered in this study play a significant role in explaining the variables of the primary study. Statistically this study proves that the Hawthorne effect, level, and sample size affect the effectiveness of PBL on mathematical thinking skills. These findings can assist educators in designing classroom settings to improve students' mathematical thinking skills.

Keywords: Effect sizes, Mathematical thinking, Meta-analysis, Problem-based learning.

1. Introduction

Enhancing the ability of the 21st century for each individual with consideration of universal needs such as the ability to solve problems and literacy is the goal of the most recent educational policy [1, 2]. In mathematics education curriculum, mathematical problem-solving, literacy, communication, critical, and creative thinking skills are very important and needed by students, so it is necessary to teach mathematics, and Learning Mathematics [3-6]. In order to obtain quality educational outcomes including in the help of problem-solving and literacy, one must be done through practicing the thinking using the Right learning model [7, 8] Mathematical problem-solving capabilities can be improved through the use of appropriate learning models [9].

National Council of Teacher of Mathematics also mentioned that the general goal of learning mathematics is to develop students' ability to set 5 standards of the mathematics learning process. One of which is to convey ideas or communication [10]. In fact, students are highly required to have good mathematical communication skills in learning and communicating it. Nowadays, critical thinking is considered as an important ability that students must have in order to face the increasingly fast and complex change in the world [11] and be able to solve the problems of daily life [12].

Critical thinking is an ability to think rationally, reflective, focused on the truth of a decision that is being carried out [13] and being able to control itself in order to produce interpretations, analyses, evaluations, and conclusions [14]. Besides, critical thinking models consist of thinking correctly, the right way, reasonably, and meritoriously [15]. In mathematics, critical thinking skill is defined as the ability to combine the initial knowledge with mathematical reasoning abilities that can be used to solve mathematical problems [16]. Thus, it can be concluded that critical thinking is a high-level thinking ability to help someone in making, evaluating, and determining the right decision related to what is believed. One of the popular learning models applied in schools is Problem Based Learning (PBL).

The PBL is a learning model aimed at preparing students to develop high-level skills such as problem-solving [17, 18]. The Weaver PBL in education practice continues to have a huge impact on all subjects and disciplines around the world [19-21], over the years demonstrating increased results in the application [22]. A variety of LBL research that uses experimental design or experimental quasi largely ensures the effectiveness of the LBL in the improvement or achievement of problem-solving and mathematical literacy skills [7, 23-33], several other researchers identified the opposite [34, 35]. Thus the PBL shows heterogeneity in its effectiveness [19, 36, 37], there has been no single study explaining that the LBL is consistently effective.

The variability of the results of primary research on PBL raises questions. For example, what should be the ideal class size in PBL, which school level is recommended in PBL, and whether the period of PBL implementation also moderates the variability of the results. Unfortunately, the preliminary study could not answer this question. On the other hand, teachers and curriculum makers need objective information about how big the effect of PBL is and what conditions need to be considered in implementing it to achieve maximum results.

It is possible to bridge this gap by conducting meta-analytical studies summarising preliminary research results to provide useful information for practice or policy [38-40]. Meta-analysis is the most objective way of summarizing primary research results because it uses effect sizes as the unit of analysis [41-45]. Through a meta-analysis procedure, we summarize the results of primary research on PBL and analyse the relationship between study characteristics and the variability of research results to consider designing classroom teaching.

In a meta-analysis, the data is expressed by a measure which is then processed and used to make statistical conclusions [46, 47]. This measure is referred to as an effect size, and a quantitative index used to summarize the results of studies in a meta-analysis [48]. The combined effect size of each primary study reflects the magnitude of the effect of PBL on students' mathematical thinking skills.

Several meta-analysis studies have been conducted [49] by examining the effectiveness of PBL on mathematics learning outcomes. Then, other people [36, 37, 50-54] have conducted a meta-analysis of the effects of PBL on competence in reasoning, communication, connection, problem-solving, and critical thinking skill. However, no specific meta-analysis study summarizes all primary studies on various students' mathematical abilities. In addition, previous meta-analyses have not considered the Hawthorne effect identified from the role of years of study as a moderator.

This study complements previous research by combining all primary studies on PBL and adding an analysis of the Hawthorne effect. By analysing the year of study as a possible moderator to explain the variability of results between studies, this study will provide a Hawthorne effect that must be considered in designing teaching. This study also considers the recommendations of the previous meta-analysis by extending the literature search strategy not only to online databases but also through hand searches and by contacting the pre-authors of the article. In this way, these findings will be more coherent and accurate. In order to achieve this goal, this research focuses on the following issues:

- Does the use of the PBL produce a more significant effect size on students' problem-solving, mathematical literacy, mathematical communication, creative mathematical thinking, and mathematical creative thinking skills than conventional approaches?
- Does the effect size of students' problem-solving, mathematical literacy, mathematical communication, creative mathematical thinking, and mathematical creative thinking skills on the implementation of PBL between study groups vary in terms of the study year, education level, and sample size?

2. Method

2.1. Research design

The method applied in this study is a meta-analysis, which is to analyse all primary studies on the effects of PBL with a systematic procedure. The procedure is carried out in in several stages, namely: defining the problem and determining the inclusion criteria; literature search and data coding; evaluate study quality (publication bias & sensitivity analysis); analyse the data statistically and make interpretations [55, 56]. In this study, we have used these stages.

2.2. Inclusion criteria

The inclusion criteria in this study are as follows: PBL research results documented throughout Indonesia published in 2011 - 2020 which are indexed by Sprott or

Google Scholar to improve problem-solving and mathematical literacy; experimental (quasi) PBL results with the control group; studies with a minimum treatment duration of 3 weeks; and primary studies which did not contain sufficient information were excluded from the analysis.

2.3. Literature search and data coding

The literature search results found 55 studies of problem-solving and 16 studies of literacy, 19 studies of creative thinking, 12 studies of communication, and 12 studies of critical thinking skills those fit the inclusion criteria. Characteristics of the sample studied, namely: sample size and level of education.

2.4. Bias analysis of publication dan sensitivity

The accuracy of the data is obtained from five stages of publication bias analysis.

(1) Analysing the funnel plot and testing the unsymmetric of the funnel plot results using a linear regression test of Egger [57]..

(2) perform the Fill and Trim test (Duval & Tweedie, 2000).

(3) Comparing the effect size,

(4) Determining the number of "null" effect studies needed to create an opportunity from an average effect to a 95% confidence level via the fail-safe estimate based on the Rosenthal procedure [48].

(5) test the sensitivity of the findings by using the "One study removed" tool on the Comprehensive Meta-Analysis (CMA) application to identify the abnormal potential sources of the data effect size [58].

2.5. Statistical analyses

The Hedges equation was chosen for the size effect measurement in this study. This is because the sample sizes of the studies conducted are relatively small [59], and Cohen's classification of interpretations of the effect size [60], as follow in Table 1.

Table 1. Classification of Cohen's effect sizes.

Effect Size (ES)	Interpretation criteria
$0,00 \leq ES < 0,20$	Very small
$0,20 \leq ES < 0,50$	Small
$0,50 \leq ES < 0,80$	Moderate
$0,80 \leq ES < 1,30$	High
$1,30 \leq ES$	Very high

Furthermore, the Q homogeneity test is conducted to determine the model effect size used in analysing all studies, the estimation model used is the random effect model [61], and for comparison test statistic Z. If the result of homogeneity test shows that the effect size of the studies is different than the investigation of several characteristics of the sample is likely to cause its heterogeneous effect size [62]. All calculations of this statistical analysis use the CMA application.

3. Results and Discussion

3.1. Analysis of publication bias and sensitivity

The publication bias of research can be in the form of a tendency for a researcher only to publish significant results of his research or a tendency for publishers to publish only significant articles or writings in his research. So it needs to be analysed the quality of the studies involved in the meta-analysis study [48, 57, 63, 64]. In order to check publication bias, funnel plots are used (Fig. 1) and assess the expected relationship between effect sizes and standard research errors. Funnel plots are often used to assess the presence of bias [48]. The distribution of effect size data from this study is presented in Figs. 1(a) to (e).

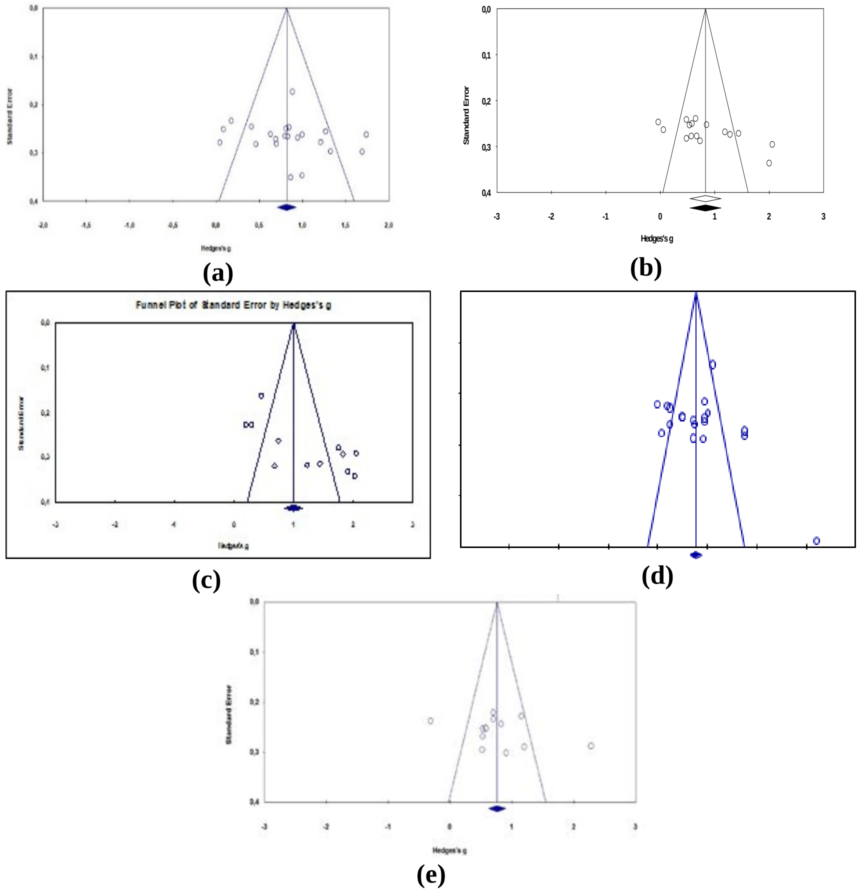

Fig. 1. Funnel Plot of Effect Size (a) Problem solving, (b) Mathematical literacy, (c) Communication, (d) Critical thinking, (d) Creative thinking.

The black diamond sign in the funnel plot shows the combined virtual ES and the blank points showing the distribution of study ES that appears to be spread evenly around the symmetry axis, meaning that it does not need to be added or subtracted due to publication bias. In other words, no publication bias was found in this study. Then three quantitative assessment methods are used: trim and fill [63], Egger regression tests [57], and Fail-safe N [65]. Neither method proves the presence or absence of publication bias. N Rosenthal's fail-safe method helps determine the probability of publication bias because distribution channel plots are not fully symmetrical. From the analysis of data with the help of CMA software, N Rosenthal's fail-safe value is 600. According to the formula, N/(5k+10) with k is the number of studies [66], which is 600/(5×16 +10), the calculation result is 6.667.

According to these calculations, it can be identified that the studies included in this analysis are resistant to publication bias because when the calculation results> 1 show sufficient tolerance to publication bias. Thus it is stated that the results of the meta-analysis in this study are reliable. The funnel plot in Fig. 1 provides an overview of the effect size distribution in a vertical line in which the effects are combined. Here, there is no publication bias found when the distribution of effect size is symmetrical toward the combined effect size. In the presented funnel plot, it can be seen that the dots which represented the effect size is located symmetrically high enough toward the combined effect size. Besides, there is no study that shows the effect size is too far from the vertical line. Thus, it can be argued that no studies need to be excluded or added as a result of the impact of publication bias.

As explained in Fig. 1, the effect size is spread almost symmetrically in the center of the funnel plot, but there are 2 data scattered on the left and right side of the funnel plot. However, based on the Fail Save N (FSN) calculation, the N Rosenthal value is 334. According to the formula N / (5K + 10) [67] with a k value of 12, it is obtained 334/(5×12 +10) = 4.771. According to this calculation, because the statistical calculation result is 4.7771>1, this meta-analysis is resistant to publication bias, and this research is reliable.

3.2. Overall study effect size

In determining the effect size model used, a homogeneity test is performed. The results of the homogeneity effect size test calculations from the studies conducted are shown in Table 2.

Table 2. Comparison of meta-analysis results based on the effect model.

Math Ability	Model	N	Hedge's g	95% CI	Null Hypothesis Test (2-Tail)		Heterogeneity		
					Z	*p*	*Q*-value	df(Q)	*p*
Problem solving	FE	55	0.81	[0.70;0.92]	14.62	0.00	58.97	54	0.00
	RE	55	0.82	[0.64;1.01]	8.76	0.00			
Mathematical Literacy	FE	16	0.78	[0.65;0.91]	11.75	0.00	67.234	15	0.00
	RE	16	0.83	[0.55;1.10]	5.85	0.00			
Critical Thinking	FE	12	1.00	[0.07;1.17]	13.21	0.00	82.887	11	0.00
	RE	12	1.201	[0.31;1.39]	5.64	0.00			
Creative Thinking	FE	19	0.77	[0.66;0.88]	14.00	0.00	95.62	18	0.00
	RE	19	0.82	[0.56;1.07]	6.29	0.00			
Communication	FE	12	0.76	[0.61;0.90]	10.31	0.00	56.78	11	0.00
	RE	12	0.791	[0.46;0.72]	4.70	0.00			

Based on the results of the heterogeneity analysis in Table 2 that the *p* value is less than 0.05, which indicates that the overall mathematical problem solving ability and mathematical literacy through PBL have significant differences. With a p value of less than 0.05 in the heterogeneity analysis indicates that the random-effect rather than fixed-effect model [61]. So that the next process can use a random-effect model as a basis for conducting analysis. The null hypothesis test results from the random-effect model in Table 2 show that the p value is less than 0.05, which indicates from 22 studies conducted that the mathematical problem solving ability and 16 studies for mathematical literacy have a large effect size of 0.828 based on [60]. These findings are similar to previous findings [19, 53, 68-70].

3.3. Study moderator analysis results

The heterogeneity of sample and publication characteristics are factors that are likely to cause heterogeneous mathematical problem-solving abilities of PBL implementation. So it is important to do an analysis of these factors [62]. Calculation results from the analysis of items in sample characteristics and publications are shown in Table 3.

Table 3. Results of study characteristics analysis.

Study Characteristics		Category	*N*	Hedge's g	Heterogeneity		
					Q_b	df(Q)	*p*
Sample Sizes	Problem Solving	≤ 30 ≥ 31	33 22	0.85 0.79	0.08	1	0.77
	Literacy	≤ 30 ≥ 31	6 10	0.73 0.88	0.27	1	0.59
	Critical thinking	≤ 30 ≥ 31	5 7	1.46 1.02	1.07	1	0.29
	Communication	≤ 30 ≥ 31	4 8	0.77 0.75	0.01	1	0.89
	Creative thinking	≤ 30 ≥ 31	5 14	0.67 0.79	0.71	1	0.39
Education Level	Problem solving	Elementary Junior Senior College	2 17 1 2	1.22 0.81 0.17 0.89	4.16	3	0.24
	Creative thinking	Elementary Junior Senior College	3 9 3 4	0.85 0.47 0.70 0.70	6.80	2	0.07
	Mathematical Literacy	Junior Senior	12 3	0.72 0.85	1.65	2	0.31
	Critical thinking	High School Vocational	9 3	1.14 1.38	0.23	1	0.63
Year of Study	Problem Solving	2012-2014 2015-2017 2018-2020	7 22 26	1.02 0.93 1.13	0.05	2	0.81
	Mathematical Literacy	2012-2014 2015-2017 2018-2020	4 4 7	1.11 0.62 0.51	5.96	2	0.13
	Critical thinking	2012-2014 2015-2017 2018-2020	4 5 4	0.77 0.71 0.82	438	1	0.03
	Creative thinking	2012-2014 2015-2017 2018-2020	7 2 8	1.03 0.68 0.66	55.68	2	0.00
	Mathematical Communication	2012-2014 2015-2017 2018-2020	2 3 7	0.91 0.66 0.77	2.12	2	0.57

The results were not much different from the research of [36] but different from [62] in his studies on ICT literacy skills demonstrated that the characteristics of education levels, sampling techniques, area studies, and publication status have significant differences. A significant difference in sample size characteristics, education levels, sampling techniques, area studies, and publication status in [67], and [62]. Because of the study they did more than the study conducted in this meta-analysis study, which is as many as 95 studies in [67] and as many as 46 studies in [62].

3.3.1. Sample size.

The effect of PBL on increasing mathematical problems and critical thinking, at a sample size of less than 31 participants was high, and moderate for a sample size of at least 31, except for critical thinking, which was the same for both groups of participants. As for literacy, creative thinking, and mathematical communication skills, a study that was followed by less than 30 participants showed more effective results. The effect of implementing PBL for a sample size of less than 31 participants which is better on improving problem solving appears to be the opposite in increasing mathematical literacy. However, hypothesis testing shows that the p-value is less than 0.05 for a sample size of less than 31 participants and a sample size of at least 31 participants. It can be interpreted that the improvement of both types of mathematical thinking can be significantly improved through PBL. The same thing is found in the results of their study and [36].

3.3.2. Education level

Descriptive Effect size at the elementary school level is the largest 1.224 than for junior school (0.817) and for colleges by 0.894, while for high school is quite negligible 0.178 can be ignored. Thus, in descriptively that the implementation of the PBL to improving mathematical problem-solving at the elementary level is better than junior high school, senior high school, or college. As for the mathematical literacy implementation of the PBL is very suitable in college. The hypothesis testing shows that the p's value is fewer than 0.05 for elementary, junior, or higher level. It interprets that the ability of mathematical problem-solving by implementing the PBL significantly greater than by implementing conventional learning is reviewed from the participant's education level. The results were in line with the research of [36] but differed from [53], and [62]. The low effect size in the high school level in this study can be due to the number of studies done very little. From the above explanation, confirms that the PBL is more effective to improve mathematical problem-solving than to improve mathematical literacy.

3.3.3. Year of study

Year of Study. Judging from the year of research, there are hydrogen results for all types of mathematical competences. In terms of mathematical problems, the effect of PBL is lower in the 2015-2017 period than in other periods. The effect on literacy and mathematical creative thinking achieved is better in the initial period with high quality and decreases in the next period until 2020 with moderate quality. In the aspect of mathematical communication, the influence of PBL has still not reached that category in nearly a decade. These findings indicate a Hawthorne effect in implementing PBL. This happens when students feel happy and motivated only because of the novelty of the treatment [71].

4. Conclusions

A meta-analysis of 55 articles on PBL authority on mathematical problem ability and 16 articles on mathematical literacy, 19 articles on mathematical creative thinking, 12 articles on mathematical critical thinking, and 12 articles on mathematical communication, illustrates the strengths of PBL in developing thinking skills. Mathematics with general effect sizes has medium and high effect quality.

- Based on the inclusion assessment, to improve problem-solving abilities, PBL can be applied at all grade levels, especially in elementary and middle schools with a size of less than 31, while for increasing mathematical literacy PBL is more directed to be applied at a higher level.
- The effectiveness of the application of PBL seems to be more successful in improving critical thinking skills, with the highest impact, especially for middle school students, while the increase in mathematical communication skills and creative thinking is categorized as moderate. Based on the results of the analysis in terms of sample size, if the sample size is ≤ 30 students, the PBL effect value is higher than the sample size> 30, which is the opposite of the impact on increasing mathematical literacy.
- Judging from the study year, it becomes the basis for findings outside the applied analysis of the effectiveness of the use of PBL on students' mathematical thinking abilities. There is a tendency that the application of PBL for the first time or in the early period has a more significant impact on students' thinking.
- While this does not imply a publication bias, it is hypothesized that significant study results are likely to be published will need to be retested. For this reason, further studies need to be carried out, to provide mathematics educators with a complete picture of PBL's authority in mathematics classrooms.

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