The effect of problem-based learning on students’ mathematical problem-solving skills in some countries: A meta-analysis from the angle of study heterogeneity

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**Abstract**. Until now, researchers have been researching mathematical problem-solving skills (MPSS) supported by problem-based learning (PBL). However, the literature shows various inconsistent research results. Whereas educators need accurate information, under whether conditions the PBL implementation can improve students’ MPSS. This study was conducted to combine and interpret the findings of primary studies on the PBL effect by analysing the heterogeneity of studies through meta-analysis methods. Research findings from 56 studies that conform to the inclusion criteria were included in the meta-analysis. Heterogeneity analysis was conducted by analysing the effect of mediator variables, namely the sample and publication characteristics. The analysis tool used the Comprehensive Meta-Analysis (CMA) application by selecting the Hedge's equation to determine its effect size. The results of the study showed that the overall PBL implementation had a moderate positive effect (ES = 0,789) on the students’ MPSS in some countries based on a random-effect model. The heterogeneity of the PBL effect on MPSS was not significantly affected by the sample characteristics. However, descriptively the PBL implementation in improving students’ MPSS should be applied to classes with less than or equal to 32 students. Likewise, the PBL implementation in improving students’ MPSS could be applied at any education level.

1. Introduction

Until now, the mathematical problem-solving skills supported by problem-based learning has been extensively studied by researchers in various countries. From the results of several studies conducted in Indonesia, Thailand, Nigeria, Vietnam, Turkey, and Pakistan, researchers have argued that PBL has a positive effect on the students’ mathematical problem-solving skills [1-5], while several other researchers have identified that PBL has no effect or negative effect [6-10]. This shows a variety of research results that are not consistent. On the other hand, educators especially mathematics teachers need accurate information, under whether conditions the implementation of PBL can improve the students’ mathematical problem-solving skills.

Some PBL research results that are not consistent in improving the students' mathematical problem-solving skills can be caused by various characteristics of the sample, for example, education level, sample size, research area, and others [11]. So, in this study, researchers investigated the effect of PBL on students’ mathematical problem-solving skills in some countries by investigating various characteristics of samples and publications through a meta-analysis study. Meta-analysis is a quantitative research method that analyses various studies that have been done previously to determine the strength of the relationship between several variables with statistical analysis that uses specific measures, such as effect size [12-14].

Some previous meta-analysis studies on the effectiveness of PBL in improving problem-solving skills still have some weaknesses. Analysis of publication bias and sensitivity is needed to guarantee the quality of a study [15]. However, there are still several meta-analysis studies that have not to analyze publication bias and sensitivity [16-23]. As a result, the size of the resulting combined effect tends to be over-interpreted and does not reflect the actual effect. Investigating the characteristics of a sample and a publication is needed in analyzing the heterogeneity of a meta-analysis study results. But several meta-analysis studies have not investigated the sample characteristics [22-23]. Likewise, some meta-analysis studies have not investigated the publication characteristics [17,20]. So that there are characteristics that are likely to cause heterogeneity of effect size but are not investigated and analyzed.

This study aimed to integrate the findings of both the whole study and based on the study characteristics extracted from various primary studies by answering the following questions:

1. What is greater the students’ mathematical problem-solving skills by implementing PBL than the students’ mathematical problem-solving skills by implementing conventional learning in some countries significantly?
2. What do the sample characteristics significantly affect the heterogeneity of the PBL effect on students’ mathematical problem-solving skills in some countries?
3. Methods
   1. Research Design

The meta-analysis method was the method used in this study. As a method, meta-analysis had a systematic procedure, namely: first, defining the problem and determining inclusion criteria; second, searching for literature and coding data; third, evaluating study quality (analysis of publication bias and sensitivity); and fourth, analysing data statistically and make interpretations [24]. The same procedure was used in this study.

* 1. Inclusion Criteria

This study used a variety of inclusion criteria. Firstly, analysing research documents in Indonesia, Thailand, Vietnam, Turkey, Pakistan, and Nigeria which were published in 2010 – 2020 indexed by Scopus or non-Scopus. Secondly, analysing the result of the research contained in the experimental group (PBL) and the control group (conventional learning). Thirdly, analysing the result of research with a quasi-experiment with a causal-comparative type. So that primary studies that did not contain adequate information were excluded from the analysis.

* 1. Literature Search and Coding Data

The results of the literature search using the search engine of google scholar, semantic scholar, institute of education science (ERIC), IOP science, science direct, Francis & Taylor journal, SAGE publication Inc, and Sinta were found 60 studies, but only 56 studies were by the inclusion criteria in the form of international and national journals and proceedings. To investigate in testing the effectiveness of PBL on the students’ mathematical problem-solving skills, the studies were coded based on sample and publication characteristics [11]. To complete the statistical information in calculating the effect size of several primary studies, communication via e-mail was made with the principal researcher.

* 1. Bias Publication and Sensitivity Analysis

Several analyses were carried out in analysing publication bias. Firstly, analysing the funnel plots and the asymmetries of the funnel plot results using Egger's linear regression test [25-26]. Secondly, doing the fill and trim test [27]. Thirdly, comparing effect sizes based on studies that were indexed by Scopus and non-Scopus [28]. Fourthly, determining the number of “null” effect studies needed to make the probability of an average effect to 0,05 through the estimation of fail-safe N based on the Rosenthal procedure [12]. Finally, analysing the sensitivity of the findings by using the “One study removed” tool in the CMA application to identify potential abnormal sources of effect size data sets [24].

* 1. Static Analysis

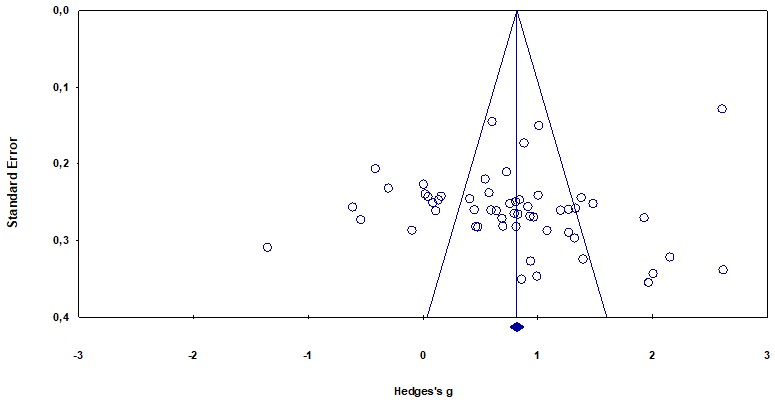
In this study, the Hedge's equation was used to determine the effect size. Because the sample sizes of the studies conducted were relatively small [29]. Cohen’s effect size classification was used in this study [30]. Cohen's effect size classification is presented in Table 1.

|  |  |
| --- | --- |
| **Table 1.** The Cohen’s effect size classification | |
| **Effect Size (ES)** | **Interpretation** |
|  | Ignored |
|  | Small |
|  | Moderate |
|  | Large |
|  | Very Large |

In determining the effect size model used in analysing these studies then homogeneity tests were performed. If then the null hypothesis was rejected which indicated that the effect sizes of the studies were different. So the estimation model used was a random-effect model [13]. After that, we did a comparison test to examine the hypothesis. If then the null hypothesis was rejected [12]. Finally, if the homogeneity test results showed that the effect size of these studies was different, then it was necessary to analyse several characteristics of samples that were likely to cause heterogeneity of these effect sizes [11]. All calculations and tests performed in this statistical analysis used the Comprehensive Meta-Analysis (CMA) application.

1. Result and Discussions
   1. Publication Bias and Sensitivity Analysis

The publication of the results of a study could not be separated from bias. So it needed to be analyzed the quality of the studies involved in the meta-analysis study [12,25-27]. The distribution of effect size data from 56 studies conducted is presented in Figure 1.



**Figure 1**. The funnel plot of Hedge’s standard error

Figure 1 shows that the distribution of effect size data from studies carried out symmetry or spread evenly showing that the students’ mathematical problem-solving skill to implement PBL was diverse and spread evenly. Egger’s linear regression test results showed that the funnel plot was symmetric with . To find out how many studies should be added or removed from a meta-analysis study, fill and trim test was performed. Calculation results from fill and trim tests are presented in Table 2.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Table 2**. The results of the fill and trim test | | | | | | |
|  | Studies Trimmed | Random Effect Model | | Fixed Effect Model | | Q-value |
| Hedge’s g | 95% CI | Hedge’s g | 95% CI |
| Observed Values |  | 0,789 | [0,577; 1,000] | 0,819 | [0,754; 0,883] | 576,084 |
| Adjusted values | 0 | 0,789 | [0,577; 1,000] | 0,819 | [0,754; 0,883] | 576,084 |

Table 2 shows that no study should be trimmed or filled to the meta-analysis study conducted. Then, the homogeneity test of publication characteristics on the publication status indexed by Scopus in Table 5 does not provide strong evidence that studies indexed by Scopus ( and indexed by non-Scopus ( differed significantly with dan . After that, the fail-safe N analysis based on the Rosenthal procedure showed that the Rosenthal's fail-safe N value was 7.888. This means that we need to find and include 7.888 "null" studies so that a combined 2-tailed p-value exceeds to 0,05. This shows that the studies conducted have resistance to publication bias. Thus, some publication bias analysis did not provide strong evidence of publication bias from studies conducted which indicated that studies conducted in this meta-analysis tend to have a small risk of publication bias.

Outliers can play a significant role in the distortion in the averages and the variability of a set of effect sizes. So that sensitivity analysis can be used to identify sources that had the potential to make a collection of effect sizes abnormal [24]. In Table 4, it can be seen that the overall effect contained in the random-effect model was . By using the tool “One study removed” in CMA application with random-effect models obtained that the highest mean was and the lowest mean was . This shows that the collection of effect sizes is extremely stable and reasonable which is not affected by an abnormal combination of effect sizes and sample sizes. Thus, it could be concluded that the overall findings of differences in the students’ mathematical problem-solving skills from implementing PBL and conventional learning were not sensitive to abnormal effect sizes and sample sizes.

* 1. The Overall Effect Size of Study

The overall effect size of PBL implementation on students’ mathematical problem-solving skills in some countries from each study is presented in Table 3.

**Table 3**. Effect size from each study

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| No | Authors | Effect Size | No | Authors | Effect Size |
| J01 | Saragih dkk, 2018 | 1,008 | J29 | Amperawan dkk, 2018 | -0,298 |
| J02 | Pohan dkk, 2020 | 2,010 | J30 | Gunawan dkk, 2017 | 0,450 |
| J03 | Siregar dkk, 2018 | 1,399 | J31 | Putri dkk, 2018 | 1,085 |
| J04 | Darma, 2017 | 1,970 | J32 | Minarni, 2012 | 0,411 |
| J05 | Hobri dkk, 2020 | 0,023 | J33 | Khayroiyah & Ramadhani, 2018 | 0,885 |
| J06 | Puncreobutr & Rattana., 2016 | -1,352 | J34 | Ayu dkk, 2016 | 0,644 |
| J07 | Sahyar & Fitri, 2017 | 1,203 | J35 | Rahman dkk, 2018 | 0,996 |
| J08 | Fatade dkk, 2013 | 0,732 | J36 | Partasiwi, 2019 | 0,799 |
| J09 | Astriani dkk, 2017 | 0,941 | J37 | Octaria & Sari, 2017 | 2,621 |
| J10 | Ali dkk, 2010 | 0,007 | J38 | Afrilia dkk, 2014 | 0,936 |
| J11 | Ajai dkk, 2013 | 2,612 | J39 | Elita dkk, 2019 | 0,831 |
| J12 | Darma dkk, 2018 | 1,969 | J40 | Sa’bani, 2017 | 0,863 |
| J13 | Karatas & Baki, 2013 | 0,816 | J41 | Rinaldi & Afriansyah, 2019 | 0,482 |
| J14 | Riswari dkk, 2018 | 0,969 | J42 | Ratnasari & Yulia, 2018 | -0,609 |
| J15 | Ramadhani, 2018 | 0,048 | J43 | Rizka, 2018 | -0,412 |
| J16 | Hendriana dkk, 2018 | 0,918 | J44 | Marbun, 2020 | 0,138 |
| J17 | Ruchaedi dkk, 2016 | 0,761 | J45 | Aprianti dkk, 2018 | 1,932 |
| J18 | Yanti, 2017 | 2,156 | J46 | Laili, 2019 | 0,700 |
| J19 | Angkotasan, 2013 | 1,486 | J47 | Zulaiha dkk, 2016 | 0,546 |
| No | Authors | Effect Size | No | Authors | Effect Size |
| J20 | Untarti, 2015 | 0,162 | J48 | Mulyani dkk, 2018 | 1,333 |
| J21 | Miranti dkk, 2015 | 0,845 | J49 | Asis dkk, 2017 | 1,383 |
| J22 | Lestari dkk, 2016 | 0,597 | J50 | Ferdianto dkk, 2018 | -0,540 |
| J23 | Nahdi, 2018 | 0,087 | J51 | Yenni dkk, 2017 | 0,464 |
| J24 | Suparptinah dkk, a, 2015 | 0,114 | J52 | Rohmawati dkk, 2019 | 0,812 |
| J25 | Supraptinah dkk, b, 2015 | 0,606 | J53 | Sutrisno dkk, 2020 | 1,325 |
| J26 | Setiawan dkk, 2014 | 1,013 | J54 | Aisyah, 2016 | 1,274 |
| J27 | Sumartini, 2016 | 0,692 | J55 | Wahyu & Ginting, 2017 | 1,272 |
| J28 | Nadhifah & Afriansyah, 2016 | 0,579 | J56 | Mawarti dkk, 2018 | -0,093 |

Table 3 shows that the range of effect sizes of the PBL implementation on students' mathematical problem-solving skills was between -1,352 and 2,621. Based on Cohen's effect size classification, twelve studies had a very large effect size, seventeen studies had a large effect size, ten studies had a moderate effect size, four studies had a low effect size, seven studies had negligible effect size, and six studies had negative effect size.

In determining the effect size model used, a homogeneity test was performed. The result of the homogeneity effect size test calculation from the studies conducted is shown in Table 4.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Table 4.** Comparison of meta-analysis results based on effect models | | | | | | | | |
| Model | Number Studies | Hedge’s g | 95% CI | Null Hypothesis Test (2-Tail) | | Heterogeneity | | |
| Z-value | p | Q-value | df(Q) | p |
| Fixed | 56 | 0,819 | [0,754; 0,883] | 24,855 | 0,000 | 576,084 | 55 | 0,000 |
| Random | 56 | 0,789 | [0,578; 1,000] | 7,321 | 0,000 |  |  |  |

Based on the results of the heterogeneity analysis in Table 4 indicates that the overall effect size of studies conducted had a significant difference. Besides, the p-value was less than 0,05 in the heterogeneity analysis which indicates that the random-effect model was significantly better than the fixed-effect model [13]. So that the next process used a random-effect model as a basis for conducting the analysis. The results of the null hypothesis test from the random-effect model in Table 4 show that from 56 studies conducted in some countries, the students’ mathematical problem-solving skill by implementing PBL was significantly greater than the students’ mathematical problem-solving skill by implementing conventional learning with an effect size of 0,789 and based on Cohen’s effect size classification belonged to a moderate effect size. These findings were similar to the previous findings, Kadir et al which has shown that the overall problem-solving skill in mathematics and science learning from implementing PBL was 1,079 which was classified as a large effect size with 16 studies conducted [20]. Besides, Puyada et al in the results of their research in 20 studies conducted has shown that PBL had a more positive effect on student learning outcomes [22]. Then, Dochy et al in their meta-analysis study of 40 studies has shown that PBL had a significant effect in developing an understanding of concepts and principles, and understanding in applying concepts and principles in condition and procedure [18]. In another meta-analysis study, Gijbels et al in their 25 studies has shown that PBL was significantly effective in increasing knowledge and skills [19]. The implementation of PBL which is effective on the students’ mathematical problem-solving skill is caused the design of PBL, students are helped to build their knowledge broadly and flexibly, develop themselves as individuals who can apply their abilities and skills under various conditions, develop effective problem-solving skills that include the skill to apply strategies meta-cognitive and appropriate reasoning, and develop learning ability independently and throughout time [31-33].

* 1. The Heterogeneity of The Sample and Publication Characteristics

The heterogeneity of the sample and publication characteristics was factors that are likely to cause heterogeneous students’ mathematical problem-solving skills from implementing PBL. So it was important to analyse these factors [11]. Calculation results from the analysis of items in sample and publication characteristics are presented in Table 5.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Table 5**. Summary of analysis results of sample and publication characteristics | | | | | | | | |
| Study Characteristics | Group | Number Studies | Hedge’s g | Null Hypothesis Test  (2-Tail) | | Heterogeneity | | |
| Z-value | p |  | df | p |
| **Sample** |  |  |  |  |  |  |  |  |
| Sample Size | Partisipant | 33 | 0,805 | 5,641 | 0,00 | 0,029 | 1 | 0,866 |
| Partisipant | 23 | 0,767 | 4,604 | 0.00 |
| Education Level | Elementary School | 7 | 0,995 | 3,372 | 0,00 | 3,372 | 3 | 0,338 |
| Junior High School | 32 | 0,631 | 4,613 | 0,00 |
| Senior High School | 12 | 1,062 | 4,776 | 0,00 |
| College | 5 | 0,854 | 2,415 | 0,02 |
| Research Area | Domestic | 50 | 0,824 | 7,268 | 0,00 | 0,902 | 1 | 0,342 |
| Abroad | 6 | 0,498 | 1,535 | 0,12 |
| **Publication** |  |  |  |  |  |  |  |  |
| Publication Year | 2010 - 2012 | 2 | 0,454 | 0,830 | 0,41 | 2,148 | 4 | 0,709 |
| 2013 - 2014 | 6 | 0,995 | 3,111 | 0,00 |
| 2015 - 2016 | 12 | 0,650 | 2,850 | 0,00 |
| 2017 - 2018 | 28 | 0,752 | 5,003 | 0,00 |
| 2019 - 2020 | 8 | 1,062 | 3,745 | 0,00 |
| Status Indexed by Scopus | Scopus | 7 | 0,847 | 6,724 | 0,01 | 0,040 | 1 | 0,841 |
| Non-Scopus | 49 | 0,781 | 2,752 | 0,00 |
| Publication Type | Journal | 51 | 0,759 | 6,658 | 0,00 | 0,788 | 1 | 0,375 |
| Proceeding | 5 | 1,099 | 3,004 | 0,00 |

Based on the heterogeneity analysis in Table 5 that all the characteristics of sample and publication did not significantly affect the heterogeneity of the effect of PBL on students’ mathematical problem-solving skills in some countries. Demirel & Dagyar in their study of the PBL effect on attitudes has shown similar results that there were no significant differences in the characteristics of the education level and sample size [34]. Likewise, Batdi in his study of the PBL effect on attitudes has shown similar results that there were no significant differences in the characteristics of education level [17]. However, it was different from Siddiq and Scherer in their study of ICT literacy skills, they have shown that the characteristics of education level, research areas, and publication status had significant differences [11]. The difference in results from several meta-analysis studies on the characteristics of sample size, education level, research area, and publication status can be due to the number of studies conducted differently, the proportion of the number of studies of the components in each sample and publication characteristic is different, and the effect size of each study is also different.

*3.3.1. The Heterogeneity of Study Based on The Characteristic of Sample Size*

In some countries, the students’ mathematical problem-solving skill by implementing PBL is significantly greater than the students’ mathematical problem-solving skill by implementing conventional learning in terms of sample size. Descriptively that the implementation of PBL on a sample size of less than or equal to 32 participants is better than a sample size of more than 32 participants. Tamur et al in their study also has shown a similar thing that a sample size of less than or equal to 30 participants was better than a sample size of more than 30 participants [35]. Likewise, Demirel & Dagyar in their study has shown that a sample size of less than or equal to 32 participants was better than a sample size of more than 32 participants [34]. So, descriptively, it is better if PBL implementation in improving students’ mathematical problem-solving skills is applied to classes where the number of students is less or equal to 32 people.

*3.3.2. The Heterogeneity of Study Based on The Characteristic of Education Level*

In some countries, the students’ mathematical problem-solving skill by implementing PBL is significantly greater than the students’ mathematical problem-solving skill by implementing conventional learning in terms of the participant education level. Descriptively that the implementation of PBL at senior high school level is better than at elementary school, junior high school, and college level. Tamur et al, Siddiq & Scherer, and Demirel & Dagyar in their study have shown different things that in the characteristics of the education level, the implementation of PBL at elementary school level was better than at junior & senior high school and college-level [11,34-35]. So that the implementation of PBL in improving students’ mathematical problem-solving skills can be applied at any education level because there are no results of meta-analysis studies that consistently show that PBL implementation is very effectively applied at certain levels of education.

*3.3.3. The Heterogeneity of Study Based on The Characteristic of Research Area*

In Indonesia, the students’ mathematical problem-solving skill by implementing PBL is significantly greater than the students’ mathematical problem-solving skill by implementing conventional learning. However, in some countries such as Thailand, Nigeria, Vietnam, Turkey, and Pakistan, the students’ mathematical problem-solving skill by implementing PBL is not significantly greater than the students’ mathematical problem-solving skill by implementing conventional learning. Descriptively that the implementation of PBL in improving students’ mathematical problem-solving skills is more effectively applied in Indonesia than in some countries such as Thailand, Vietnam, Turkey, Nigeria, and Pakistan.

1. Conclusion and Recommendation

A meta-analysis of 56 primary studies illustrated that the magnitude of the effect of PBL in improving students’ mathematical problem-solving skills in Indonesia, Thailand, Vietnam, Turkey, Pakistan, and Nigeria was 0,789 classified in moderate effect size. Sample characteristics such as sample sizes, education levels, and research areas did not have a significant effect on the heterogeneity of the implementation of PBL in improving students’ mathematical problem-solving skills in some countries. However, descriptively, PBL implementation in improving students’ mathematical problem-solving skills should be applied to classes with less or equal to 32 students. Likewise, the implementation of PBL in improving students’ mathematical problem-solving skills could be applied at any education level. In this meta-analysis study, there were still some weaknesses such as the number of primary studies, the number of literature search engines, and primary studies indexed by Scopus which was still relatively small. Some sample characteristics such as the experiment duration time, the sampling technique, and the study year conducted were not observed. So, for next meta-analysis studies especially on the topic of the effect of PBL on the students' mathematical problem-solving skills, multiply the number of primary studies, the number of literature search engines, and primary studies indexed by Scopus. Likewise, involving the characteristics of the sample such as the experiment duration time, the technique sampling used, and the study year conducted because these could have the probability to affect the heterogeneity of effect size.

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