Review of problem-based learning trends in 2010-2020: A meta-analysis study of the effect of problem-based learning in enhancing mathematical problem-solving skills of Indonesian students

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Abstract. The present study analyzes various inconsistent research findings on the effect of problem-based learning (PBL) in enhancing students’ mathematical problem-solving skills (MPSS) in Indonesia. A meta-analysis of 50 primary studies that conform to the inclusion criteria was conducted to summarize, estimate, and evaluate findings of the effect of PBL by analyzing the heterogeneity of the studies. Heterogeneity analysis was conducted by analyzing the effect of moderator variables, namely the characteristics of sample and publication. The analysis tool used the Comprehensive Meta-Analysis (CMA) application by selecting the Hedge’s equation to determine its effect size. The "One study removed" tool in the CMA application was used to analyze the sensitivity of effect size data, and publication bias was assessed by the funnel plot, fill and trim test, and Rosenthal’s fail-safe N test. The findings of the study showed that the overall implementation of PBL had a larger positive effect significantly compared to conventional learning on the students’ MPSS in Indonesia based on a random effect model. The characteristics of the education level and research area significantly affected the heterogeneity of the effect of PBL on students’ MPSS. Thus, these findings suggest that mathematics teachers and lecturers should choose PBL as one of the best solutions in implementing Mathematics learning in the classroom to enhance MPSS. Furthermore, they should pay attention and consider the education level of students and the area where students learn in implementing PBL in enhancing students’ MPSS.

1. Introduction

Until now, the students’ mathematical problem-solving skills (MPSS) supported by problem-based learning (PBL) has been widely studied by researchers in Indonesia. The researchers have said that PBL had a positive effect on the students’ MPSS [1-4], while several researchers have identified that PBL had no effect or negative effect on students’ MPSS [5-8]. This indicated a variety of the results of research that were not consistent. On the other hand, education policymakers especially mathematics teachers need accurate information such as how many students, at what education level, and with how long the treatment duration of the implementation of PBL can enhance the students’ MPSS.
Several results of PBL research that were not consistent in enhancing the students’ MPSS can be affected by various characteristics of the sample and publication, such as publication type, sample size, publication year, and others [9]. Thus, researchers investigated the effect of PBL on students’ MPSS in Indonesia by investigating various characteristics of samples and publications through a meta-analysis method in this study. Meta-analysis is a quantitative research method that analyzes 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 [10-12].

Several previous meta-analysis studies on the effect of PBL in enhancing problem-solving skills still had some disadvantages. Analysis of publication bias and sensitivity is needed to guarantee the quality of a study [13]. However, there were still several meta-analysis studies that have not analyzed publication bias and sensitivity [14-21]. Then, the size of the resulting combined effect tended to be over-interpreted and did not reflect the actual effect. Investigating the characteristics of sample and publication is needed in analyzing the heterogeneity of a meta-analysis study results. However, several meta-analysis studies have not investigated the characteristics of sample characteristics [20-21] and the characteristics of publication [15,18]. Therefore, there were characteristics that were likely to affect heterogeneity of effect size but were not investigated and analyzed. Thus, this study aimed to summarize, estimate, and evaluate the overall effect of PBL towards students’ MPSS in Indonesia by integrating 50 relevant primary studies and the overall characteristics of sample and publication.

2. Methods
2.1. Research Design
The meta-analysis was the method used in this study. It had a systematic step, namely: first, defining the problem and determining inclusion criteria; second, searching for literature and coding data; third, evaluating study quality; and fourth, analyzing data statistically and make interpretations [22]. The same steps were used in this study.

2.2. Selection Study
To select the primary study, this study used a variety of inclusion criteria. Firstly, analyzing research documents in Indonesia which were published in 2010 – 2020 indexed by Scopus or non-Scopus. Secondly, analyzing the result of the research contained in the experimental group (PBL) and the control group (conventional learning). Thirdly, analyzing the result of research with a quasi-experiment with a causal-comparative type. Thus, the primary studies that did not contain adequate information were excluded from the analysis.

2.3. Literature Search Strategy and Extracting Data
By using the databases of google scholar, semantic scholar, institute of education science (ERIC), IOP science, science direct, Francis & Taylor journal, and SAGE publication Inc, we found 56 primary studies, but only 50 primary studies were relevant with the inclusion criteria. In order to investigate the effect of PBL on the students’ MPSS, the primary studies were coded based on the characteristics of sample and publication [9]. To complete the statistical information in calculating the effect size of several primary studies, communication via e-mail was made with the principal researcher.

2.4. The Validity of Statistic Data of Each Primary Study
In validating primary studies that were included in the meta-analysis process, analysis of publication bias and sensitivity was conducted because the publication of the results of a study was not free from bias [13,22]. Therefore, it was necessary to analyze the quality of the primary studies involved in the meta-analysis study. To see the spread of the data of effect size, the funnel plot analysis was performed [23]. The distribution of effect size data from 50 primary studies conducted is presented in Figure 1. It shows that the distribution of effect size data from primary studies was symmetry or spread evenly that indicated that the students’ MPSS through the implementation of PBL was diverse and spread evenly.
To find out how many primary studies should be added or removed from a meta-analysis study, a fill and trim test was performed [24]. The results of the calculation from the fill and trim test are presented in Table 1.

**Table 1. 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 | 0.817 [0.640; 0.994]| 0.746 [0.676; 0.816]| 305.869 |
| Adjusted values | 0.817 [0.640; 0.994]| 0.746 [0.676; 0.816]|         |

The results of the fill and trim test show that there was no study that had to be trimmed or filled to the meta-analysis study conducted. Then, to determine the resistance of studies from publication bias, the Rosenthal’s fail-safe N analysis was performed [10]. The results of the Rosenthal’s fail-safe N analysis show that the Rosenthal’s fail-safe N value was 6.020, and the p-value was less than 0.05. This revealed that it was necessary to search for and include 6.020 “null” studies for the combined 2-tailed p-value to exceed $\alpha = 0.05$. This implies that the primary studies processed in this meta-analysis were resistant to publication bias. Thus, some publication bias analysis did not provide strong evidence of publication bias which indicated that the primary studies conducted in this meta-analysis tended 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. Therefore, the analysis of sensitivity can be used to identify sources that had the potential to make a collection of effect sizes abnormal [22]. The overall effect contained in the random-effect model was $g = 0.817$; 95% CI $= [0.640; 0.994]$; $n = 50$; SE $= 0.090$. By using the tool “One study removed” in CMA application with random-effect models obtained that the highest mean was $g = 0.845$; $n = 50$; SE $= 0.088$ and the lowest mean was $g = 0.782$; $n = 50$; SE $= 0.087$. This indicates that the collection of effect sizes was extremely stable and reasonable which was 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’ MPSS after the implementation of PBL and conventional learning were not sensitive to abnormal effect sizes and sample sizes.
2.5. Statistical Analysis

The Hedge's equation was used to determine the effect size in this study because the sample sizes of the primary studies conducted were relatively small [25]. Cohen’s effect size classification was used in this study [26]. Cohen's effect size classification is presented in Table 2.

| Effect Size (ES) | Interpretation |
|------------------|----------------|
| 0.00 ≤ ES < 0.20 | Ignored        |
| 0.20 ≤ ES < 0.50 | Small          |
| 0.50 ≤ ES < 0.80 | Moderate       |
| 0.80 ≤ ES < 1.30 | Large          |
| 1.30 ≤ ES        | Very Large     |

To determine the effect model used in analyzing these studies, the heterogeneity tests were performed. Suppose \( Q_p > \chi^2_{0.95}; p < 0.05 \), the null hypothesis was rejected, which indicated that the effect sizes of the studies were different. Therefore, the estimation model used was a random-effect model [11]. Then, we did a comparison test to examine the hypothesis. Suppose \( Z_{\text{hitung}} > Z_{\text{table}}; p < 0.05 \), the null hypothesis was rejected [10]. Finally, if the heterogeneity test results showed that the effect size of these studies was different, it was necessary to analyze several characteristics of samples and publications that were likely to affect heterogeneity of these effect sizes [9]. All calculations and tests performed in this statistical analysis used the Comprehensive Meta-Analysis (CMA) application.

3. Result and Discussions

3.1. The Overall Effect Size of Each Primary Study

To determine the effect model used, the heterogeneity test was performed. The result of the heterogeneity test from the studies conducted is shown in Table 3.

| Model    | Number of Studies | Hedge’s g | 95% CI       | Null Hypothesis Test (2-Tail) | Heterogeneity |
|----------|------------------|-----------|--------------|-------------------------------|---------------|
|          |                  |           |              | Z-value | P-value | Q-value | df(Q) | P-value |
| Fixed    | 50               | 0.746     | [0.676; 0.816] | 20.903 | 0.000   | 305.869 | 49    | 0.000   |
| Random   | 50               | 0.817     | [0.740; 0.904] | 9.050  | 0.000   |          |        |         |

The results of the heterogeneity analysis in Table 3 indicate that the overall effect size of primary studies conducted had a significant difference. Besides, the p-value was less than 0.05 in the heterogeneity analysis which indicated that the random-effect model was significantly better than the fixed-effect model [11]. 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 3 show that from 50 primary studies conducted in Indonesia, the students’ MPSS after the implementation of PBL was significantly higher than the students’ MPSS after the implementation of conventional learning and based on Cohen’s effect size classification belongs to a large effect size. These findings were similar to the previous findings, Kadir et al., which showed that the overall effect size of problem-solving skills in mathematics and science learning after the implementation of PBL was 1.079, classified as a large effect size with 16 primary studies conducted [18]. Besides, Puyada et al., in the results of their research in 20 primary studies conducted showed that the implementation of PBL had a more positive effect on student learning outcomes [20]. Then, Dochy et al., in their meta-analysis study of 40 primary studies showed that the implementation of PBL had a significant effect in developing an understanding of concepts and principles, and understanding in applying concepts and principles in condition and procedure [16]. In another meta-analysis study, Gijbels et al., in their 25 primary studies, showed that the implementation of PBL was significantly effective in increasing knowledge and skills [17]. The implementation of PBL which is effective on the students’ MPSS was affected by 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 [27-29].

3.2. The Heterogeneity of The Characteristics of Sample and Publication
The heterogeneity of the characteristics of sample and publication was considered factors that might cause variation in the effect size of the implementation of PBL on students’ MPSS. Therefore, it was important to analyze these factors [9]. The calculation results from the analysis of items in the characteristics of sample and publication are presented in Table 4.

| Study Characteristics | Group                        | Number Studies | Hedge’s g | Null Hypothesis Test (2-Tail) | Heterogeneity |
|-----------------------|------------------------------|----------------|-----------|------------------------------|---------------|
|                       |                              |                |           | Z-value          | P-value | Q<sub>b</sub> | df | P-value |
| Sample                | ≤ 32 Participants            | 30             | 0.896     | 7.524           | 0.00    | 1.051 | 1     | 0.305   |
|                       | > 32 Participants            | 20             | 0.707     | 5.025           | 0.00    |        |       |         |
| Education Level       | Elementary School            | 6              | 1.160     | 4.501           | 0.00    |        |       |         |
|                       | Junior High School           | 31             | 0.622     | 5.615           | 0.00    |        |       |         |
|                       | Senior High School           | 9              | 1.028     | 4.986           | 0.00    |        |       |         |
|                       | College                      | 4              | 1.391     | 4.358           | 0.00    |        |       |         |
| Research Area         | Bali & Nusa Tenggara         | 5              | 1.155     | 4.074           | 0.00    |        |       |         |
|                       | Java                         | 21             | 0.655     | 4.891           | 0.00    |        |       |         |
|                       | Kalimantan                    | 2              | 0.731     | 1.682           | 0.09    | 10.28 | 4     | 0.036   |
|                       | Maluku & Sulawesi            | 2              | -0.182    | -0.416          | 0.67    |        |       |         |
|                       | Sumatera                     | 20             | 1.021     | 7.284           | 0.00    |        |       |         |
| Sampling Technique    | Purposive Sampling           | 21             | 0.837     | 5.934           | 0.00    |        |       | 0.032   |
|                       | Random Sampling              | 29             | 0.804     | 6.710           | 0.00    |        |       | 0.858   |
| Publication Year      | 2010 - 2012                  | 1              | 0.885     | 1.387           | 0.17    |        |       |         |
|                       | 2013 - 2014                  | 3              | 0.558     | 1.448           | 0.15    |        |       |         |
|                       | 2015 - 2016                  | 11             | 0.819     | 4.088           | 0.00    | 1.500 | 4     | 0.827   |
|                       | 2017 - 2018                  | 27             | 0.779     | 6.023           | 0.00    |        |       |         |
|                       | 2019 - 2020                  | 8              | 1.051     | 4.373           | 0.00    |        |       |         |
| Status Indexed by     | Scopus                       | 5              | 1.016     | 8.308           | 0.00    |        |       | 0.528   |
|                       | Non-Scopus                   | 45             | 0.795     | 3.522           | 0.00    |        |       | 1.050   |
| Publication Type      | Journal                      | 45             | 0.788     | 8.230           | 0.00    |        |       | 0.966   |
|                       | Proceeding                   | 5              | 1.087     | 3.763           | 0.00    |        |       | 1.026   |

The heterogeneity analysis in Table 4 shows that the characteristics of the education level and research area significantly affected the heterogeneity of the effect of PBL on the students’ MPSS in Indonesia. Siddiq & Scherer, in their study, showed a similar result that the characteristics of the education level and research area significantly affected the heterogeneity of primary studies [9]. On the other hand, the characteristics of sample size, sampling technique, publication year, publication type, and Scopus indexed status did not significantly affect the heterogeneity of the primary studies. Demirel and Dagyar, in their study, showed similar results in that there was no significant difference in the characteristics of the sample size [30]. Furthermore, Tamur et al., in their study, showed similar results that there was no significant difference in the characteristics of publication type and publication year [31-32]. However, it was different from Siddiq & Scherer, in their study that the characteristics of the sampling technique and publication status significantly affected the heterogeneity of the primary studies [9]. The difference in the results of several meta-analysis studies on the characteristics of sampling technique and publication status could be due to the different number of primary studies conducted, the
proportion of the number of primary studies of the components in each the characteristics of sampling technique and publication status was different, and the effect size of each study was also different.

Based on the sample size that in Indonesia, the students’ MPSS after the implementation of PBL was significantly higher than the students’ MPSS after the implementation of conventional learning. The implementation of PBL on a sample size of less than or equal to 32 participants was higher than the sample size of more than 32 participants. Tamur et al., in their study, also showed a similar thing that a sample size of less than or equal to 30 participants was higher than the sample size of more than 30 participants [31-33]. Furthermore, Demirel & Dagyar, in their study, showed that a sample size of less than or equal to 32 participants was higher than the sample size of more than 32 participants [30]. Thus, it was better if the implementation of PBL in enhancing students’ MPSS was applied to classes where the number of students was less or equal to 32 people.

Furthermore, in Indonesia, the students’ MPSS after the implementation of PBL was significantly higher than the students’ MPSS after the implementation of conventional learning in terms of the participant education level. Significantly, the implementation of PBL at the college level was higher than at elementary school, junior high school, and senior high school level. Tamur et al., Siddiq & Scherer, and Demirel & Dagyar, in their study, showed different things that in the characteristics of the education level, the implementation of PBL at elementary school level was higher than at junior & senior high school and college-level [9,30-31,33]. Thus, the implementation of PBL in enhancing students’ MPSS could be applied at any education level because there were no results of meta-analysis studies that consistently showed that the implementation of PBL was very effectively applied at certain levels of education.

Besides, specifically in Bali & Nusa Tenggara, Sumatera, and Java, the students’ MPSS after the implementation of PBL was significantly higher than the students’ MPSS after the implementation of conventional learning. However, in Kalimantan, Sulawesi, and Maluku, the students’ MPSS after the implementation of PBL was not significantly higher than the students’ MPSS after the implementation of conventional learning. Significantly, the implementation of PBL in enhancing the students’ MPSS in Indonesia was higher applied in Bali & Nusa Tenggara than in Java, Sumatera, and Kalimantan, Sulawesi, and Maluku. However, these findings could not be generalized in general because the comparison of the number of primary studies in each area was not proportional.

On the other hand, based on the sampling technique used in the sample selection that in Indonesia, the students’ MPSS after the implementation of PBL were significantly higher than the students’ MPSS after the implementation of conventional learning. The implementation of PBL in which research in selecting samples using purposive sampling was higher than using random sampling techniques. Siddiq & Scherer, in their study, showed different things that the effect size of using a random sampling technique was higher than purposive sampling [9]. This difference could be due to the quite different proportions between the number of primary studies using random sampling technique and purposive sampling technique. In Siddiq & Scherer, the proportion of the number of primary studies between the use of random sampling technique and purposive sampling technique was 37:9 while in this study, the proportion was 29:21.

Studies published in 2015-2020 reported that students’ MPSS after the implementation of PBL were significantly higher than students’ MPSS after the implementation of conventional learning. However, studies published in 2010-2014 reported that students’ MPSS after the implementation of PBL were not significantly higher than students’ MPSS after the implementation of conventional learning. The findings of studies published in 2015-2020 indicated that the implementation of PBL as an effort to enhance students’ MPSS in Indonesia was getting higher and more massive. This finding was indicated by the effect size which had increased from year to year and the increasing number of the implementation of PBL in schools in mathematics learning to enhance students’ MPSS.

Furthermore, studies that were indexed by Scopus did not differ significantly from primary studies that were not indexed by Scopus. These findings interpreted that both Scopus and non-Scopus indexed studies had the same opportunity to be included in the meta-analysis process in this study. However, descriptively, the effect size of primary studies indexed by Scopus was higher than the effect size of
primary studies that were not indexed by Scopus. Another similar finding suggests that the primary studies published in the journal type did not differ significantly from those published in the proceeding. Tamur et al., in their study, demonstrated a similar finding that neither the primary studies published in the journal nor the proceedings were significantly different [31,33]. This finding indicated that primary studies published in the journal and proceedings had the same quality and the same opportunities for inclusion in the meta-analysis of this study. However, descriptively, the effect size of studies published in the type of proceedings was higher than the effect size of studies published in journal type.

4. Conclusion
The study of a meta-analysis of 50 primary studies estimated that the effect of PBL in enhancing students’ MPSS in Indonesia was 0.817 classified in larger effect sizes. Thus, these findings suggest that mathematics teachers and lecturers should choose PBL as one of the best solutions in implementing Mathematics learning in the classroom to enhance MPSS. Then, the characteristics of education levels and research area significantly affected on the effect size of the implementation of PBL in enhancing students’ MPSS in Indonesia. Conversely, the characteristics of the sample size, sampling technique, publication year, Scopus indexed status, and publication type did not affect significantly the effect size of the implementation of PBL in enhancing students' MPSS in Indonesia. Thus, mathematics teachers should consider the education level of students and the area where students learn in implementing PBL in enhancing students’ MPSS.

There were still some disadvantages such as the relatively small number of primary studies, the relatively small number of literature search engines, and the relatively small primary studies indexed by Scopus in this meta-analysis study. Some sample characteristics such as the treatment duration and the study year conducted were not observed. Therefore, for further meta-analysis studies especially on the topic of the effect of PBL on the students’ MPSS, multiplying the number of primary studies, the number of literature search engines, and the primary studies indexed by Scopus. Furthermore, involving the characteristics of the sample such as the treatment duration and the study year conducted because these could have the probability to affect the heterogeneity of effect size.

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