A meta-analysis study of the effect of Problem-Based Learning model on students’ mathematical problem solving skills

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Abstract. This study aims at analysing the effectiveness of Problem-Based Learning (PBL) on students’ mathematical problem-solving skills. The Effect Size in some research which applied PBL was examined using the meta-analysis technique. Empirical data were obtained using electronic search engines, including Google Scholar, Portal Garuda, ERIC, SPRINGER, and national journals URL; coding was used as the instrument. Data analysis was conducted using the meta-analysis software, namely Comprehensive V.03. The method included systematic reviews on research findings in Indonesia's national e-journals, with 16 articles meeting the inclusion criteria selected as the sample. The publication bias test was carried out so that 13 articles were obtained which would be analysed further. The meta-analysis study reveals that the overall effect of implementing PBL on students’ mathematical problem-solving skills had a high category of effect. Moreover, the effect size of the application of the PBL model on solving ability between study groups was not different based on the characteristics of the level of education, class, sample size, and study year. The results of other studies, it was found that there was a significant difference in the effect size between study groups based on the duration of learning.

1. Introduction
Mathematics is very important to learn at every level of education and can be the basis of other sciences [1]. Based on the objectives of learning mathematics as stated by the National Council of Teachers of Mathematics (NCTM) in 2002, one of the abilities that need to be developed in mathematics learning is the problem-solving skills. Besides, solving problem abilities are part of the mathematics skills that students must have [2]. Therefore, in learning mathematics, students must develop the solving problem abilities.

Problem-solving is the essence of mathematics, so problem-solving has an important role in learning mathematics [2]. Problem-solving has referred to as an attempt to identify a problem that exists in everyday life. The problem-solving steps has understanding, planning, implementing according to plan, and checking back the results obtained [3]. A learning model that can motivate students to take an active role and focus on problem-solving is the problem-based learning (PBL) model [4]. PBL model stages:
Students are problem-oriented, direct students to learn, help students explore both groups and individually, elaborate and show work, and analyse the problem-solving process [5].

The number of previous studies carried out in Indonesia to assess the effect of PBL on the mathematical problem-solving abilities of junior and senior high school students (Mawaddah & Yulianti, 2014; Sukmawati & Sari, 2015; Andes Safarande Asmara, 2016; Amiati, et al., 2018; Yulius, et al., 2017; Nusyahidan & Albab, 2018; Juna & Supiati, 2019). However, the results of these studies do not have consistent values, and the results of these studies have not included the PBL effect size value on students' mathematical problem-solving abilities. The effect of PBL application on the mathematical problem-solving abilities of junior and senior high school students and the influence of learning characteristics cannot be answered through primary research [6]. Thus, it needs to be re-analysed using meta-analysis techniques with a systematic review method. A systematic review results from a systematic literature search, where all articles are obtained and combined for careful analysis [7]. In a systematic review, a formal statistical analysis is called a meta-analysis. Meta-analysis analyses the results of previous studies with the same case and model to get universal conclusions [9].

A meta-analysis study conducted by Dochy et al. (2003) stated that the combined effect size calculation results statistically showed that students who studied in the PBL class were better at applying their knowledge and developing their skills. [10]. The same is the case with the research results obtained by Gijbels et al. (2005) who argued that students who studied PBL showed better understanding and knowledge than students who studied in conventional classrooms. Their research focused on the effectiveness of PBL on problem-solving abilities [11]. Meanwhile, Anugrahendi (2018) obtained the results of a meta-analysis of the effect of implementing PBL being able to develop critical thinking skills that are still limited at the elementary school level [12]. Then, research conducted by Asror (2016) only analysed the effect of the study criteria, namely math skills, subject matter, learning media, and education level [13]. However, previous research is still limited to the characteristics of the research design, the field of implementation, the level of student expertise, and the type of assessment. Thus, this meta-analysis study aims to determine the effect of PBL on students' problem-solving abilities based on the characteristics of the level education, class, sample size, year, and duration of learning study. Thus, this meta-analysis study can provide holistic results of the influence of PBL on students' mathematical problem-solving abilities to evaluate their application and see overall trends.

2. Method
The research method used in this research is a systematic review research method with a meta-analysis research approach. The population in this study was a national mathematics education research journal related to the influence of PBL on problem-solving abilities from 2014 to 2019 (January to December). The sample in this study was 16 articles on mathematics education in Indonesia meeting the inclusion criteria. Data collection techniques were library searches using electronic search engines, such as Google Scholar, Portal Garuda, ERIC, SPRINGER, and national journals URL. It aims to determine the quality of journals containing the measurement of science and technology performance, including the performance of researchers, writers, authors, journal performance and the performance of science and technology institutes called SINTA. This research defines the problem, collecting available literature, converting and correcting statistical information, determining the average of the data obtained, and considering variations in observed effects.

The use of the effect size has related to meta-analysis. The effect size is used to represent the effect of the independent variable on the dependent variable, and the value will be compared in each primary study. This technique is used to calculate the effect size of PBL on students' mathematical problem-solving abilities using the Hedges' formula [9]. Interpretation of the effect size uses the classification used by Tamur et al. [14].
### Table 1. Category of the Effect Size.

| Effect Size (ES) | Category         |
|------------------|------------------|
| -0.15 ≤ 0.15     | Negligible effects |
| 0.15 < ES ≤ 0.40 | Small effect     |
| 0.40 < ES ≤ 0.75 | Medium effect    |
| 0.75 < ES ≤ 1.10 | High effect      |
| 1.10 < ES ≤ 1.45 | Very high effect |
| 1.45 > ES        | High influence   |

Another important analysis should also be carried out in a meta-analysis study, namely, the publication bias test. This test is needed to avoid research published by journals with significant research results so that the effect size is larger than the actual effect size [8]. The publication bias test can be done by looking at the funnel plot results, namely if the combined effect size spreads symmetrically, there is no bias in the articles being analysed. From the results of the FSN value obtained from the formula N / (5k - 10) > 1 (k is the number of studies involved), it can be interpreted that all analysed studies are not prone to publication bias and reliable interpretation. Then, trim and fill tests were correlated with funnel plots to ascertain the number of studies that led to publication bias and exaggerated interpretation of effect sizes [15].

Each meta-analysis study effect size, combined effect size, and effect size on each moderator variable, as well as publication bias, were analysed using the help of Comprehensive Meta-Analysis (CMA) V 3.0 Software.

### 3. Result and Discussion

#### 3.1. Results

The results of the search for electronic machines indexed by Google Scholar, Garuda Portal, and national journal URLs obtained 45 articles related to the effect of PBL on the problem-solving abilities of junior high school and high school students. However, the study results based on inclusion criteria found only 16 articles to be analyses. The effect size of each article is presented in table 2 as follows:

### Table 2. Overall Effect Size.

| No | Article Code | Year | Hedge’s | Effect Size Category |
|----|--------------|------|---------|----------------------|
| 1  | A16          | 2016 | -0.293  | Which can be ignored  |
| 2  | A01          | 2018 | 0.490   | Medium               |
| 3  | A06          | 2016 | 1.343   | Very high            |
| 4  | A13          | 2017 | -0.219  | Which can be ignored  |
| 5  | A25          | 2018 | 1.293   | Very high            |
| 6  | A31          | 2016 | 1.051   | High                 |
| 7  | A02          | 2017 | 1.600   | High influence       |
| 8  | A15          | 2019 | 0.655   | Medium               |
| 9  | A17          | 2019 | 0.519   | Medium               |
| 10 | A22          | 2016 | 0.579   | Medium               |
| 11 | A30          | 2016 | 0.997   | High                 |
| 12 | A20          | 2016 | 1.274   | Very high            |
| 13 | A08          | 2016 | 0.906   | Medium               |
| 14 | A28          | 2019 | 1.420   | Very high            |
| 15 | A29          | 2017 | 2.065   | High influence       |
| 16 | A18          | 2019 | 0.423   | Medium               |

**Average effect size** 0.801 High
Table 2 shows two articles with negligible effect categories, six articles with moderate effect categories, two articles with high effect categories, four articles with very high effect categories, and two articles with high effect categories. The results of the analysis using the fixed model effect showed that the influence of PBL on problem-solving ability was 0.801 with the high effect category.

Furthermore, the publication bias test was carried out using the results of the funnel plot diagram. The funnel plot is shown in Figure 1 below.

![Funnel Plot of Standard Error by Hedges's g](image)

**Figure 1.** Funnel plot of standard error by hedges’ g.

Based on Figure 1, it can be seen that the effect size value is spread almost symmetrically in the middle of the funnel plot. Note that the effect size spread is not completely symmetrical, so an FSN value is identified to calculate the probability of publication bias. The result of the FSN value obtained with the help of CMA software is 671. With the results obtained based on the formula is $7.455 > 1$. The results of this publication bias test indicate that the analysed study is not susceptible to publication bias. Then, the results of the trim and fill tests can be seen in Table 3 below:

**Table 3.** Publication Bias with Trim and Fill Tests.

| Random Effect Size | Omitted studies | Point estimate | Lower limit | Upper limit | Q-Value |
|--------------------|-----------------|----------------|-------------|-------------|---------|
| Observed value     | 3               | 0.868          | 0.548       | 1.187       | 93.363  |
| Adjusted value     |                 | 0.683          | 0.354       | 1.013       | 137.439 |

Based on Table 3, the trim and fill test results show the observed effect size value of 0.868 and the adjusted effect size value of 0.683. Then it was discovered that three articles had to be eliminated, namely J13, J16, and J18. Next, identify heterogeneity of effect size distributions. Based on the CMA output, the heterogeneity value is presented in Table 4 below:

**Table 4.** Heterogeneity of the Effect of Size Distribution.

| Heterogeneity | Q-value | df(Q) | P-value | I-squared | Q-table |
|---------------|---------|-------|---------|-----------|---------|
| Q-value       | 36.000  | 12    | 0.000   | 66.667    | 21.026  |
Table 4 shows that the Q-Value is 36,000 > the Q-table value ($\alpha = 5\%$), namely 21,026. This shows that the heterogeneity of the effect size distribution affects the estimation model used in this analysis is the random effect model. The random effect model assumes a population effect size that is normally distributed around the mean value and standard deviation. The effect size results based on the effect random model from 13 studies found that the limit was 0.827 and the upper limit was 1.333 with an average effect size of 1.080 with the high effect category. As a calculation of the Z test to determine statistical significance, the Z score was 8.359 and a p-value < 0.05.

Further analysis was carried out to see the effectiveness of PBL on students' mathematical problem-solving abilities in terms of the characteristics of the level education, class, sample size, year, and duration of learning study. The recapitulation results from the analysis of the research characteristics are obtained in Table 5 as follows.

| Study Characteristics | Group                                      | Number of Hedge’s g | Test of Null (2-Tail) | Heterogeneity Between Classes Effect (Q) | df (Q) | P     |
|-----------------------|--------------------------------------------|---------------------|-----------------------|-----------------------------------------|--------|-------|
| Education stage       | Senior high school                         | 4                   | 0.875                 | 4.438                                   | 0.000  | 1.359 |
|                       | Junior high school                         | 9                   | 1.173                 | 7.181                                   | 0.000  | 1     |
| Sample size           | ≤ 30 students                              | 5                   | 1.090                 | 6.395                                   | 0.000  | 0.004 |
|                       | > 30 students                              | 8                   | 1.075                 | 5.894                                   | 0.000  | 1     |
| Class                 | VII                                        | 5                   | 1.173                 | 4.786                                   | 0.000  | 8.422 |
|                       | VIII                                       | 3                   | 1.035                 | 3.786                                   | 0.000  | 4     |
|                       | IX                                         | 1                   | 1.600                 | 5.956                                   | 0.000  | 0.015 |
|                       | X                                          | 1                   | 0.579                 | 2.432                                   | 0.015  | 1     |
|                       | XI                                         | 1                   | 0.986                 | 4.049                                   | 0.000  | 1     |
| Duration of learning  | 2-4 meetings                               | 4                   | 1.230                 | 5.553                                   | 0.000  | 7.685 |
|                       | 5-6 meetings                               | 7                   | 1.153                 | 6.343                                   | 0.000  | 2     |
|                       | > 6 meetings                               | 2                   | 0.544                 | 3.062                                   | 0.002  | 2     |
| Study year            | 2014-2016                                  | 6                   | 1.012                 | 8.662                                   | 0.000  | 0.243 |
|                       | 2017-2019                                  | 7                   | 1.140                 | 4.887                                   | 0.000  | 1     |

Based on the results obtained in Table 5, it can be seen that all p values in the Z test for the five research characteristics are less than 0.05. These results indicate that the application of the PBL model is better than learning other than PBL in terms of research characteristics.

3.2. Discussion

The purpose of this study was to determine the effect of PBL on students' problem-solving abilities. From the results of the calculation of the combined effect size calculation analysis, it is known that PBL has a high effect on problem-solving abilities.

The estimation model selection is made by testing the heterogeneity to avoid the tendency to change the measurement value. It can be seen in Table 4 that the Q-Value is 36,000 > Q-table 21,026. This means that there is a statistically significant difference in the average effect size in each study. In other words, the results obtained are heterogeneity in the effect size distribution so that the appropriate estimation model is the random effect size. Furthermore, using a random effect model of 13 articles, it was found that the effect size value was 1,092 with a high effect category. If you look again at the effect size before the three articles were removed, it was 0.801; then there is a significant difference. Therefore, publication bias greatly influences the overall effect size. From the results of the calculation of the effect size.
size with 13 articles is 1,092, this figure shows that PBL is able to improve students' mathematical problem-solving abilities with a high effect size category.

Based on table 5, the analysis results in terms of education level show that the effect size at junior high school is 1.173, and senior high school education is 0.875. Both effect size values are categorised as high effects. Descriptively, the application of PBL is more influential in junior high school than in senior high school. For the heterogeneity test, the Q-count value is smaller than the Q-table value (1.359 < 3.841), so it can be concluded that there is no significant effect on the effect size between study groups in terms of education level.

Based on table 5, the analysis results in terms of the study class show that the effect size in class IX is 1.600 in the high influence category. The effect size for class VII is 1.173, class VIII is 1.035, and class XI is 0.986 in the high effect category. In contrast, class X is 0.578 in the medium effect category. The application of PBL to problem-solving abilities has more effect on class XI than other classes. For the heterogeneity test, it was obtained that the Q-count value was 0.004 smaller than the Q-table value of 9.487, so it can be concluded that there was no significant effect between study groups in terms of the study class.

Based on table 5, the analysis results in terms of the sample size show that the effect size obtained for the sample size \( \leq 30 \) the student was 1,090, and the sample size \( > 30 \) students are 1,075, both of the effect size scores are categorised as high effects. It can be seen that the application of PBL to problem-solving abilities has more effect on the number of samples \( 0f \leq 30 \) students. For the group heterogeneity test in terms of sample size characteristics, Q-count was 0.004 < Q-table, namely 3.841, so it can be concluded that there was no significant effect on the effect size between groups in terms of sample size characteristics.

The review analysed the duration of learning in the research article shows that the effect size value for the duration of 2-4 meetings is 1,230. For the duration of 5-6 meetings is 1,153, both effect sizes are categorised as high effects. Then for the duration > 6 meetings, it is in the moderate category. This shows that PBL on problem-solving abilities has more effect on the duration of 2-4 meetings. When viewed from the heterogeneity test, it is obtained that the Q-count is 7.685 > Q-table is 5.991, so it can be concluded that there is a significant influence between groups in terms of the characteristics of the duration of learning.

Finally, the characteristics in terms of the study year obtained by the effect size for the study group (2014-2016) were 1,012 and for the study group (2017-2019) was 1,140. The two study groups were both in the high effect category. It can be concluded that the application of PBL to problem-solving abilities is more significant in the 2017-2019 study year. It can be seen from the Q-count homogeneity test that is 0.243 > Q-table that is 3.8414, so it can be concluded that there is no significant effect on the effect size between groups in terms of the characteristics of the study year.

4. Conclusion

Based on the results of the meta-analysis conducted in this study, it can be concluded that the PBL model affects students' mathematical problem-solving abilities. First, referring to the combined effect size results with the random-effects model, the implementation of the PBL model has an effect size of 1,092 that means that the application of the PBL model has a high effect on students' mathematical problem-solving abilities. Second, it was found that the magnitude of the effect of the application of the PBL model on students' mathematical problem-solving abilities between the study groups did not differ according to the characteristics of the study class, study year, and sample size. Third, it was found that there were significant differences in effect sizes between study groups based on the duration of learning. Thus, the PBL model application is very useful and effective in improving junior and senior high school students' mathematical problem-solving abilities by considering the duration of learning at the time of implementation. These findings contribute information to educators, government, and other related parties regarding the effectiveness of PBL in the learning process. However, it is hoped that further researchers will be able to analyse more characteristics of the study.
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