Mathematics Learning Problem Based Learning Model in Improving Students' Mathematical Representation Ability: A Meta-Analysis

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Abstract
This research aims to examine the effect size of studies that discuss the application of the Problem Based Learning model as an effort to improve students' mathematical representation skills. The statistical procedures used in this study were based on the meta-analysis procedures namely: (a) calculating the effect size of each primary study; (b) conducting heterogeneity tests and selecting estimation models; (c) check for publication bias; (d) calculate the p-value to test the research hypothesis. The primary studies used were 10 studies obtained from the Google Scholar search engine with publication years between 2018 and 2024. The results of statistical calculations showed that the overall effect size of the studies used was 0.600, which is included in the moderate effect size category with a standard deviation of 0.171. This finding means that the application of the Problem Based Learning model in mathematics learning has a moderate influence on students' mathematical representation skills.
Keywords: Meta Analysis, Problem Based Learning, Representation

Introduction

Competition in the ongoing globalization period is increasingly fierce. Qualified human resources are expected to be able to face this challenge. Every country, including Indonesia, strives to improve the quality of their human resources. One way to improve the quality of human resources is through education. According to a report from the World Economic Forum, "Quality education is the key to improving workforce competitiveness in the era of globalization"(World Economic Forum, 2023)

This is in line with the function of national education in Law No. 20 of 2003 which reads "national education functions to develop abilities and shape the character and civilization of a nation that is useful in order to educate the nation's life, aims to develop the potential of students to become human beings who are faithful and devoted to God, have noble character, are healthy, knowledgeable, capable, creative, independent, and become democratic and responsible citizens."

To further develop learners' potential, it is important to expand the information they receive. One of the essential disciplines is mathematics. Mathematics is the foundation of modern science, plays an important role in teaching logic, and helps develop examples of human reasoning (Sari et al., 2024). This is in line with Government Regulation No. 19/2005 on National Education Standards which states that every level of education must include mathematics. Therefore, mathematics is an important subject that must be mastered by students.

One of the abilities demanded in learning mathematics is the ability of mathematical representation. According to the National Council of Teachers of Mathematics (NCTM, 2000) sets five standards of mathematical abilities that students must have, namely (1) problem-solving, (2) communication, (3) connection, (4) reasoning, and (5) representation. NCTM requires learning programs from pre-kindergarten to grade 12 to enable students to: (1) create and use representations to organize, record, and communicate mathematical ideas; (2) select, apply, and translate mathematical representations to solve problems; and (3) use representations to model and interpret physical, social, and mathematical phenomena. Therefore, mathematical representation skills are needed for students to discover and develop tools or ways of thinking in communicating abstract ideas.

Representation ability is a key skill that is very important for students, because it is able to transform their understanding of complex concepts into a form that is easier to understand and apply in various contexts (Dunn, 2020). This is in line with what (Truran, 2021) stated that representation ability is the core of understanding abstract concepts. With this ability, students can parse the complexity of information and understand it better.

Representation ability is a key foundation in the learning process, helping students to understand, remember, and apply information more effectively. (Chen, 2022). Through representation, students can visualize abstract concepts, facilitating more creative problem-solving and deeper thinking. (Johnson, 2021). Representation ability not only helps students in academic learning, but also in the development of critical, analytical, and creative thinking skills. (Williams, 2020).

Although representation skills are needed and important to have, in reality the representation skills possessed by students are still low. This is shown by the data of international study results or Progamme for International Student Assessment (PISA) announced by The Organization for Economic Cooperatiom and Development (OECD) in 2022. PISA results in 2022 showed that Indonesia obtained an average score of 366 which was still far from the international score of 472 and Indonesia ranked 68 out of 81 countries participating in PISA 2022 in the math category (OECD, 2023).

The solution to the above problem is through the learning process, teachers are expected to choose a learning model that can encourage students to be actively involved in learning, and students are able to present the results such as pictures, diagrams, mathematical symbols, and text or written words. This is in line with (Rasyid, 2017) saying that teachers can improve students' mathematical representation skills by applying appropriate and effective learning models. One possible alternative learning model is Problem Based Learning (PBL). PBL is a learning model that uses real-world problems as a context for students to learn about mathematical representation and to gain essential knowledge and concepts from the subject matter (Chakim, 2019).

Problem Based Learning is a learning method that requires teachers to act as facilitators. In this role, the teacher must develop students' awareness of what needs to be done in learning mathematics, and try to involve students in the learning process. The goal is to encourage students to work independently and build their own understanding. Students are given the opportunity to search, find, discuss, and try new things in solving problems related to the real world (Munir et al., 2019). This learning model allows students to be more active in expressing or interpreting their thoughts.

Problem-based learning with the PBL model is designed to help students develop thinking skills, problem-solving, and intellectual skills (Sumartini, 2015). Jaenudin stated that providing problems that ask students to provide reasons and correlate mathematical ideas is an effective way to train students' mathematical representation skills (Jenita, 2017). This will certainly develop their mathematical representation skills.

Research (Oktaviani & Farhan, 2023) showed that the PBL model significantly improved students' mathematical representation skills better than conventional learning. The quality improvement of students' mathematical representation ability using Problem Based Learning model is included in the high category. This is in line with research (Pratiwi et al., 2019)which states that the mathematical representation skills of students who follow Problem Based Learning are higher than those of students who follow conventional learning. So it can be seen that the Problem Based Learning model can be used in an effort to improve students' representation skills.

Based on the search results of Education journals in various sources on the internet, several accredited national journals were found that discuss the effectiveness or influence of the Problem Based Learning model in improving students' mathematical representation skills. This research is a meta-analysis study that aims to measure the effect size and effectiveness of the Problem Based Learning model in improving students' mathematical representation skills based on the level of secondary school education and year of publication.

Method

The type of research used in this study is meta-analysis research by analyzing several articles in accredited national journals. The results of the analyzed research are related to the effectiveness of applying the Problem Based Learning model in an effort to improve students' mathematical representation skills. The statistical procedures used in this study are based on the meta-analysis procedures by (Borenstein, 2009), namely: (a) calculating the effect size of each primary study; (b) conducting heterogeneity tests and selecting estimation models; (c) checking for publication bias; (d) calculating the p-value to test the research hypothesis. The application used to help calculate this research is Comprehensive Meta-Analysis (CMA) software. This research is a quantitative research in the form of meta-analysis using several samples of research articles obtained from accredited national journals on the Google Scholar search engine with publication years 2018-2024. To collect scientific literature that will be used, inclusion and exclusion criteria that must be met by the study articles in this study for meta-analysis are presented in Table 1.

Table 1. Table of Inclusion and Exclusion Criteria

Criteria	Data reviewed through digital literature
Inclusion	1. Publication year range 2018-2024. 2. Articles are published in national journals accredited by Sinta 1 to Sinta 5. 3. Research articles with at least one experimental class treated with the Problem Based Learning model and one control class with conventional or other learning. 4. Articles include study data such as sample size, mean, standard deviation or statistical data.
Exclusion	1. Review materials without validation 2. Selected literature is not full text

Source: Kholili, A. et al. (2021)

Data was collected on the Google Scholar search engine using the keywords “Problem Based Learning” and “Mathematics Representation Skills”. This procedure resulted in 200 articles published between 2018 and 2024. Furthermore, articles that meet the predetermined inclusion criteria were screened. Based on the screening results, 10 articles were obtained that met the criteria set.

The data analysis technique in this study used the effect size formula to find the magnitude of the effect of a study on the variable under study and compare the effect with other studies (Anwar et al., 2023). Effect size is very important because with effect size it is possible to compare the magnitude of the effect of a study on hypothesis testing with other studies. Thus, researchers use effect size analysis to determine the effectiveness of the Problem Based Learning model based on the grouping of research subjects. The data that has been collected is analyzed using the effect size formula submitted by Glass (Anwar et al., 2023), as follows:

$$ES = \frac{\overline{X_e} - \overline{X_c}}{Spooled}$$

Description:

ES : *effect size*

$\overline{X_e}$: the mean score of the experimental group

$\overline{X_c}$: the mean score of the control group.

$Spooled$: pooled standard deviation

Considering the variation in sample size between studies, this study used Hedge's g equation to determine the effect size index (Cohen, 1988). The interpretation of effect size, using Cohen's is:

Table 2. Effect Size Categories

No	***Effect Size***	**Category**
1	$ES < 0,2$	Ignored
2	$0,2 \leq ES < 0,5$	Weak effect
3	$0,5 \leq ES < 0,8$	Moderate effect
4	$0,8 \leq ES < 1,3$	Strong effect
5	$ES \geq 1,3$	Very strong effect

Source: Cohen et al. (1998)

After the effect sizes were calculated, a homogeneity test was conducted to determine the analytical model used by examining the Q statistic and p-value. If the p-value <0.05, the effect size distribution of the primary study used was heterogeneous. So that the analysis model used is a random effects model. Meanwhile, if the p-value> 0.05, the effect size distribution used is homogeneous so that the analysis model used is a fixed effect model (Tamur et al., 2020). Analysis of the level of study variation by examining moderator variables is carried out after it is determined that the chosen estimation is a random effects model (Risna et al., 2021).

An examination of publication bias is conducted to prevent misrepresentation of findings. Published studies are more likely to be included in meta-analyses than unpublished ones and this leads to concerns that meta-analysis results may overestimate true effect sizes (Borenstein, 2009). To say that the effect size data in the primary study is resistant to publication bias then look at the funnel plot. The study is said to be resistant to bias if the spread of effects shows a symmetrical distribution around the vertical line (Anjarwati et al., 2022). If the effect size is not completely symmetrically distributed around the vertical line, the Fil-Safe N (FSN) test is performed to help determine whether there is a possibility of publication bias (Gleser, 1996). If there is no publication bias, then the author can immediately continue the analysis process by using a predetermined analysis model. If the p-value <0.05, then the null hypothesis is accepted, namely the application of the Problem Based Learning model has a significant effect on students' mathematical representation skills.

Results and Discussion

Based on data collection conducted on the Google Scholar search engine and filtering, 10 studies were obtained that met the inclusion and exclusion criteria. The research was screened and analyzed based on the completeness, suitability, clarity and novelty of the research. The research data is presented in Table 3.

The main objective of this meta-analysis study was to determine the overall effect of the Problem Based Learning model on students' mathematical representation skills. The first stage of the analysis was to calculate the effect size of each primary study. Based on the overall calculation, the effect sizes of each study are presented in Table 4.

Table 3. Literature studies that met the inclusion and exclusion criteria

No.	Author	Year	Research Methodology	Level of Education
1.	Risda Damayanti1 dan Ekasatya Aldila Afriansyah	2018	*Quasi Experimental Design*	SMA
2.	Sri Hastuti Noer dan Pentatito Gunowibowo	2018	*Pre-test Post-test Control Group Design*	SMP
3.	Kikky Astria	2018	*Concurrent Embedded Strategy*	SMK
4.	Maya Nurfitriyanti	2020	*Quasi Experimental Design*	SMA
5.	Susanti, dkk	2019	*Pre-test Post-test Control Group Design*	SMP
6.	Luqman Chakim	2019	*Posttest-only Control Design*	SMP
7.	Yulia Pratiwi, dkk	2019	*Quasi Experimental Design*	SMP
8.	Novita Sari	2024	*Quasi Experimental Design*	SMP
9.	Iyam Maryati dan Vera Monica	2020	*Pre-test Post-test Control Group Design*	SMA
10.	Suwanti, dkk	2021	*Quasi Experimental Design*	SMP

Table 4. Effect Size and Standard Error Transformation

No.	Author	*Effect Size* (SE)	*Effect Size* Category	*Standard Error*
1	Risda Damayanti1 dan Ekasatya Aldila Afriansyah	-0,65	Size effect is ignored	0,920
2	Sri Hastuti Noer dan Pentatito Gunowibowo	0,35	Weak Size Effect	0,644
3	Kikky Astria	0,16	Size effect is ignored	2,024
4	Maya Nurfitriyanti	0,73	Medium Size Effect	1,968
5	Susanti, dkk	0,96	Strong Size Effect	0,196
6	Luqman Chakim	0,43	Weak Size Effect	0,948
7	Yulia Pratiwi, dkk	0,50	Medium Size Effect	0,253
8	Novita Sari	1,11	Strong Size Effect	1,467
9	Iyam Maryati dan Vera Monica	0,86	Strong Size Effect	0,416
10	Suwanti, dkk	1,59	Strong Size Effect	0,403

Based on Table 4, it was found that the overall effect size range of the selected literature studies was -0.65 to 1.59 with a 95% confidence level. Based on these results, it was found that there were 4 studies with effect size categorized as strong, 2 studies with effect size categorized as moderate, 2 studies with effect size categorized as weak, and 2 studies with effect size categorized as negligible. Furthermore, the results of the meta-analysis of selected literature studies using the fixed effect model and random effect model will be presented in Table 5.

Table 5. Effect Size Transformation for Each Study

Estimation Model	n	Z	p	*Effect Size*	Standard Error	95% CL		Q_b	P-value	I-Squared
						Lower Limit	Upper Limit			
Fixed Effect	10	6,649	0,000	0,593	0,089	0,419	0,768	32,381	0,000	72,206
Random Effects	10	3,522	0,000	0,600	0,171	0,266	0,935			

Table 5 shows a comparison of the meta-analysis results by effect model. Based on the results obtained in table 5, it appears that in terms of the fixed effects model, the lower limit of the 95% confidence interval is 0.419 and the upper limit is 0.768 with an overall study effect size of 0.593. Based on the effect size category by Cohen's, this value is categorized as a medium effect size. The next step is to test heterogeneity and select the estimation model. From table 5, the value of Q_b=32.381 and p=0.000 were obtained. Thus, the effect size distribution is heterogeneous because $p<0.05$, which means that the actual effect size varies from one study to another. Furthermore, because the p-value <0.05, it can be concluded that overall the Problem Based Learning model has a significant effect on students' mathematical representation skills. The level of variation in effect size between studies is illustrated by the I-squared value = 72.206 which means that 72.21% of the variance in the observed effect size represents the percentage of variability caused by true heterogeneity and not caused by sampling error. Therefore, it can be concluded that this study has moderate heterogeneity because 40%<I-Squared≤75%. Since the homogeneity test result is rejected, the estimation model used is the random effect model. The next step is to check for publication bias. To check for publication bias, the funnel plot presented in Figure 1 can be seen.

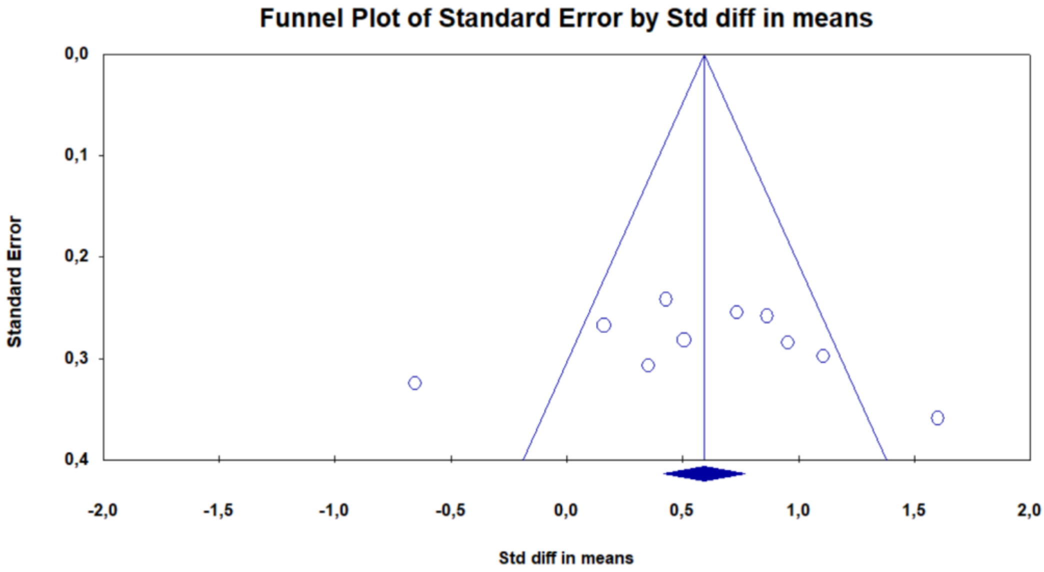

Figure 1. Funnel Plot

Based on Figure 1, it can be seen that the effect size distribution is not completely symmetrical around the vertical line. Therefore, the value of the Fail-Safe N statistic (FSN) needs to be checked. Based on calculations using CMA, the results of Orwin's fail-safe N are presented in Figure 2.

Orwin's fail-safe N

Std diff in means in observed studies	0,59346
Criterion for a 'trivial' std diff in means	0,00000
Mean std diff in means in missing studies	0,00000

Figure 1. Orwin's Fail-Safe N

Based on the results of Orwin's Fail-Safe N, Std.diff=1.79>1 was obtained. This means that the studies selected in this analysis are not resistant to publication bias. Thus, there are studies that are missing or need to be added to the analysis as a result of publication bias.

The final stage in this meta-analysis research is to calculate the p-value to test the research hypothesis. The results presented in Table 5 compare the results of the analysis according to the estimation model. Based on Table 5, it can be seen that according to the model the random effect with 95% confidence interval ranges from 0.266 to 0.955 which means that the mean difference of the analyzed studies can fall anywhere within this interval. In addition, the overall effect size of the studies is 0.600 which means that this effect size is accepted with a medium effect size category. Furthermore, the z-test calculation results obtained z=3.522. This result can be said to be statistically significant at the $p<0.001$ level. Thus, it can be concluded that the application of Problem Based Learning has a strong positive effect on students' mathematical representation skills. This is in line with research conducted by (Siagian et al., 2023) showing the results of a meta-analysis of the application of PBL is very effective on improving the representation ability of the primary study analyzed is 1.147 in the very high category. Other studies also support these findings, (Bron & Prudente, 2024) showed that PBL significantly improved mathematical skills with an overall effect of 0.58, using a random effects model, where variability between studies comes from different research characteristics, including experimental design and learning strategies used. (Paloloang et al., 2020) noted that PBL has a strong influence on mathematical representation skills at various levels of education, with an overall effect size of 0.84 which falls into the strong category. In addition, (Suparman et al., 2021) showed through meta-analysis that PBL not only improves mathematical representation ability but also mathematical communication ability, with an effect size above 0.80, emphasizing the importance of relevant problem-based problem design to maximize mathematical representation outcomes.

Conclusion and Suggestion

Based on the results of a meta-analysis conducted on 10 studies that discuss the application of the Problem Based Learning model has a moderate positive effect on students' mathematical representation skills. Based on statistical analysis, the effect size of the whole study is 0.600, which means that learning with the Problem Based Learning model has a moderate positive effect on students' mathematical representation skills. Thus, it can be concluded that overall, the application of the Problem Based Learning model significantly provides a moderate positive effect on students' mathematical representation skills compared to conventional learning models.

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