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Meta-Analysis Study: The Effect of Problem Based Learning (PBL) on Students' Mathematical Literacy Skills

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A B S T R A C T

Mathematical literacy is an important aspect of the development of students' mathematical abilities. A search was conducted through Google Scholar, Garuda, and Sintaristekbrin portals, resulting in 52 journal articles discussing the impact of implementing the problem-based learning (PBL) model on students' mathematical literacy. This study employed a meta-analysis method to investigate the influence of the PBL model on students' mathematical literacy. Twelve articles that met the inclusion criteria were selected and analyzed using the https://www.meta-mar.com platform, aiming to obtain a significant combined effect size. Based on the interpretation of the combined effect size, it can be concluded that overall, the implementation of the PBL model has a strong influence on students' mathematical literacy. The study also analyzed several study characteristics, including educational level, year of research, sample size, and geographical region of the research.

Keywords: Mathematical Literacy, Problem Based Learning, Meta-Analysis

1. Introduction

Mathematics is one of the important subjects to be understood and mastered at every level of education, starting from basic education to higher education. By learning mathematics, students will have the ability to calculate, measure, and use formulas to solve problems, as well as higher-level thinking skills in the form of problem-solving skills, reasoning skills, and critical and creative thinking skills. This is in accordance with the objectives of learning mathematics formulated by the National Council of Teachers of Mathematics (NCTM, 2000), namely that the purpose of learning mathematics is for students to have the ability to: 1) problem solve, 2) mathematical communication, 3) mathematical representation, 4) mathematical reasoning, and 5) mathematical connections. These mathematics learning objectives are very much in line with mathematical literacy or numeracy skillsThe introductory section mainly contains: (1) research problems; (2) insight and problem solving plan; (3) formulation of research objectives; (4) summary of theoretical studies related to the problem under study. This section sometimes also contains the expectations of the results and benefits of the research.

In response to the importance of mathematical literacy skills for students to master, the problem-based learning (PBL) learning model emerged as a means of learning mathematics that is more contextual and structured to achieve mathematics learning objectives. This is in line with the opinion of Rismayanti & Wahyuni (2022), which states that PBL has the definition of a systematic learning process strategy and involves students in the process of solving contextual problems through rational practice. PBL makes the problem a context where students are trained to improve mathematical literacy and try to solve the problems presented by experiencing every process in finding the solution to the problem (Awami et al., 2022). According to Ambarwati & Kurniasih (2021), PBL is a suitable learning model to improve students' numeracy literacy because the PBL learning process involves indicators of four level numeracy literacy skills such as: 1) working effectively with models in concrete and complex situations (seen in the group discussion stage); 2) selecting and representing information, including symbols, and connecting them to real situations; 3) using skills and reasoning with some knowledge in a direct context (seen in the problem-solving process); and 4) providing explanations and communicating them accompanied by reasons and arguments based on interpretations and actions (seen in the stage of presenting discussion results).

In recent years, research on the effect of the PBL learning model on mathematics learning has been the focus of attention among educational experts. A number of studies have been conducted to investigate how PBL can influence student's mathematical literacy skills. The findings from these studies provide interesting information about the benefits and challenges of implementing PBL in mathematics learning.

The purpose of this article is to conduct a meta-analysis of existing studies on the effect of PBL on student's mathematical literacy skills. Using the meta-analysis method, the authors will collect data from various relevant studies to provide a comprehensive picture of the effectiveness of PBL on student's mathematical literacy skills.

Through this meta-analysis, it is expected to provide greater insight into the potential of PBL as an effective learning model for developing student's mathematical skills, especially mathematical literacy. The results of this article are expected to assist educators, researchers, and educational practitioners in designing innovative, fun, and meaningful mathematics learning strategies..

2. Method

This research uses the meta-analysis method by analyzing several articles in national journals. Meta-analysis can be understood as a research method that involves collecting and analyzing data from previous research reports rather than surveyed individuals. Meta-analysis allows researchers to select relevant research studies, code their various characteristics and quantitative findings, and analyze and describe their collective results in a valid way (Lipsey & Wilson, 2001). The analysis was conducted on primary studies related to the application of problem-based learning (PBL) to student's mathematical literacy skills.

This research aims to conduct a meta-analysis of two or more studies that investigate the effect of PBL implementation on students' mathematical literacy skills. In this meta-analysis, the findings of the studies will be statistically and systematically combined, analyzed, and synthesized. The steps in a meta-analysis include defining the inclusion criteria for the analyzed studies, the empirical data collection procedures, describing the method of coding the study variables, and explaining the statistical techniques used (Borenstein et al., 2010). In this context, primary studies relevant to the PBL (problem-based learning) model and students' mathematical literacy skills were referred to. Articles that met the predetermined inclusion criteria were included in this analysis, including : articles searched covered a range of publication years from 2013 to 2023 and focused on research studies conducted in Indonesia and published in SINTA-indexed journals. The articles used quasi-experimental research methods with randomized control group pretest-posttest design, randomized control group posttest-only design, nonequivalent group pretest-posttest design, or nonequivalent group posttest-only design. The primary study population in these articles was elementary, junior high, and high school students in Indonesia. In searching for articles, various databases such as Google Scholar, Garuda Portal, and Sintaristekbrin kdikti were used using the keywords "problem-based learning" and "mathematical literacy skills," as well as "PBL" and "mathematical literacy skills." From this search, a total of 52 articles were found in the range of publication years 2013–2023. After making a selection based on the inclusion criteria, 12 articles were selected that met the criteria for elementary, junior high, and senior high school levels. The articles also presented statistical data such as sample size, mean, and standard deviation.

The next step was to code the studies. In this process, an instrument in the form of a coding protocol was used, which could be done manually on paper or via computer. An instruction guide is also provided to explain how to code each item based on data from the primary study (Valentine et al., 2017).

Study coding includes information such as study code, author, year of publication, mean, standard deviation, number of samples in the experimental group and control group, as well as education level and year of study. After the coding process was complete, the effect size was calculated using the standardized mean difference, or Hedges's g, using the following formula (Fritz et al., 2012) :

$$Hedges'g = \frac{M_1 - M_2}{SD^*pooled}$$

Description:

$M_1 - M_2$: difference in means

$SD^*pooled$: pooled and weighted standard deviation

The interpretation of the effect size used in this meta-analysis study is the classification according to Cohen, which is as follows (Cohen et al., 2017):

Table 1. The interpretation of the effect size

ES	Interpretation ES
0 ≤ ES ≤ 0.20	Weak Effect
0.20 < ES ≤ 0.50	Simple Effect
0.50 < ES ≤ 1.00	Moderate Effect
ES > 1.00	Strong Effect

After calculating the effect size, the next step is to conduct a homogeneity test to determine the analysis model to be used. This homogeneity test uses the p-value on the Q-statistic (Retnawati et al., 2018). If the p-value is <0.05, then the distribution of effect sizes from the primary studies in the meta-analysis is considered heterogeneous, and the analysis model to be used is the random effects model. On the other hand, if the p-value > 0.05, then the effect size distribution of the primary study is considered homogeneous, and the analysis model to be used is a fixed effect model (Retnawati et al., 2018).

Furthermore, to ensure that the studies used in this meta-analysis include all studies that address the same research question, as well as to avoid claims that only studies with significant results are published and used in this meta-analysis, the authors need to identify and address publication bias (Valentine et al., 2017). There are several methods that can be used to detect and address publication bias, such as funnel plots and Rosenthal's Fail-Safe N (FSN) (Retnawati et al., 2018). The first step in detecting publication bias is using a funnel plot. If the distribution of study effect sizes appears asymmetrical or not fully symmetrical, it is necessary to use Rosenthal's Fail-Safe N (FSN) to help determine the presence of possible publication bias (Tamur et al., 2020). If there is no indication of publication bias, the authors can continue the analysis process. Using a predefined analysis model, the authors can conduct a null hypothesis test. If the p-value is <0.05, then the null hypothesis is accepted, which means that the application of the problem-based learning model has a significant effect on students' mathematical literacy skills compared to the conventional learning model. If the analysis model used is a

random effects model, which indicates differences in study characteristics, the author can analyze the study characteristics and interpret the results of the analysis (Borenstein et al., 2010).

3. Results and Discussion

The purpose of this meta-analysis study was to estimate the combined effect size of implementing the Problem-based Learning Model on students' mathematical literacy skills.

Table 2. Studies used in the Meta-Analysis

Study code	Study Title	Year	Name of Journal
Studi 1	Meningkatkan Kemampuan Literasi Numerasi Dengan Model Problem Based Learning (PBL) Ditinjau Dari Self Confidence Siswa SMK http://ejournal.id/jm/index.php/mendidik/article/view/236	2022	MENDIDIK : Jurnal Kajian Pendidikan dan Pengajaran
Studi 2	Pengaruh Model Pembelajaran Problem Based Learning Terhadap Kemampuan Literasi Matematis dan Self Efficacy Matematika Siswa Kelas VII http://103.35.140.33/index.php/NCOINS/article/view/337	2022	NCOINS : National Conference Of Islamic Natural Science
Studi 3	Pengaruh Model Problem Based Learning Berbantuan Software Cabri 3D V2 terhadap Kemampuan Literasi Numerasi Siswa https://www.j-cup.org/index.php/cendekia/article/view/690	2021	Jurnal Cendekia : Jurnal Pendidikan Matematika
Studi 4	Problem Based Learning On Literacy Mathematics: Experimental Study in Elementary School https://e-journal.ivet.ac.id/index.php/matematika/article/view/1492	2021	Journal of Medives: Journal of Mathematics Education IKIP Veteran Semarang
Studi 5	Pengaruh Model PBL (Problem Based Learning) terhadap Kemampuan Literasi Matematika pada Pokok Bahasan Statistik Siswa Kelas XI TKR SMKN 3 Bojonegoro https://ejurnal.ikippgribojonegoro.ac.id/index.php/JTHOMS/article/view/2519	2022	J'THOMS (Journal Of Techonolgy Mathematics And Social Science)
Studi 6	Pengaruh Problem Based Learning Terhadap Kemampuan Literasi Matematis Siswa Kelas VII Di SMP Negeri 1 Bobotsari https://jurnalnasional.ump.ac.id/index.php/alphamath/article/view/7359	2018	AlphaMath : Journal of Mathematics Education
Studi 7	Kemampuan Literasi Matematis Siswa pada Pembelajaran Model Problem Based Learning (PBL) https://online-journal.unja.ac.id/edumatica/article/view/8796	2020	Edumatica : Jurnal Pendidikan Matematika
Studi 8	Kemampuan Literasi Matematika Pada Pembelajaran Problem Based Learning Berbasis Etnomatematika http://journal.upgris.ac.id/index.php/imajiner/article/view/11532	2022	Imajiner: Jurnal Matematika dan Pendidikan Matematika
Studi 9	Peningkatan Kemampuan Literasi Matematika Melalui Pendekatan Problem Based Learning Bermuatan Penilaian Portofolio https://ejurnal.ung.ac.id/index.php/Euler/article/view/13963	2022	EULER: Jurnal Ilmiah Matematika, Sains dan Teknologi
Studi 10	Penerapan Model Pembelajaran Problem Based Learning untuk Meningkatkan Kemampuan Literasi Matematis Siswa SMP https://scholar.archive.org/work/qmbjymsikbemfaybztabkv2wta/access/wayback/https://jurnal.ustjogja.ac.id/index.php/union/article/download/8115/pdf	2020	UNION: Jurnal Pendidikan Matematika

Studi 11	Pengaruh Problem Based Learning Berbantuan Media Youtube Terhadap Kemampuan Literasi Numerasi Siswa https://www.j-cup.org/index.php/cendekia/article/view/829	2021	Jurnal Cendekia : Jurnal Pendidikan Matematika
Studi 12	Penerapan Model Pembelajaran Problem Based Learning untuk Meningkatkan Kemampuan Literasi Matematis Siswa SMP https://www.neliti.com/publications/301051/penerapan-model-pembelajaran-problem-based-learning-untuk-meningkatkan-kemampuan	2019	Jurnal Didactical Mathematics

Using the help of meta-analysis calculations from the website https://meta-mar.com/, information on effect size, interpretation of effect size, standard error, and confidence interval for each study was obtained. This information is presented in the following table.

Table 3. Effect Size, Effect Size Interpretation, Standard Error, and Confidence Interval of each Study

Study Code	Year	Authors	Effect Size	Effect Size Interpretation	SE	Confidence Interval	
						Lower Bound	Upper Bound
Studi 1	2022	Fachri Awami, Yuyu Yuhana, Hepsi Nindiasari (Awami et al., 2022)	0,8618	Moderate Effect	0,2658	0,3408	1,3828
Studi 2	2022	Listia Rismayanti, Fina Tri Wahyuni (Rismayanti & Wahyuni, 2022)	4,2876	Strong Effect	0,4732	3,3601	5,2150
Studi 3	2021	Elok Rintarti Widiastuti, Meyta Dwi Kurniasih (Widiastuti & Kurniasih, 2021)	1,0232	Strong Effect	0,2381	0,5566	1,4898
Studi 4	2021	M. Farhan, Rasaning Satianingsih, Via Yustitia (Farhan et al., 2021)	1,8369	Strong Effect	0,3704	1,1110	2,5629
Studi 5	2022	Tifani Agustin, Junarti, Novi Mayasari (Agustin & Mayasari, 2022)	0,6110	Moderate Effect	0,2643	0,0930	1,1290
Studi 6	2018	Ajie Dina Kis Pujianti (Astuti, 2020)	0,6114	Moderate Effect	0,3460	-0,0667	1,2896
Studi 7	2020	Heka M. Tabun, Prida N.L Taneo, Farida Daniel (Tabun et al., 2020)	3,3087	Strong Effect	0,4004	2,5240	4,0935
Studi 8	2022	Dewi Sesanti Qauliyah, Nizaruddin, Ali Shodiqin (Qauliyah et al., 2022)	0,6633	Moderate Effect	0,2494	0,1745	1,1520
Studi 9	2022	Valeria Suryani Kurnila, Margaretha Badus, Eufrasia Jeramat, Gabariela Purnama N. (Kurnila et al., 2022)	1,8025	Strong Effect	0,2975	1,2194	2,3856
Studi 10	2020	Nita Nurul Muharomah, Erwan Setiawan (Muharomah & Setiawan, 2020)	0,7787	Moderate Effect	0,2967	0,1971	1,3603

Studi 11	2021	Dyah Ambarwati, Meyta Dwi Kurniasih (Ambarwati & Kurniasih, 2021)	0,7782	Moderate Effect	0,2446	0,2987	1,2577
Studi 12	2019	Ade Sriwahyuni, Jajang Rahmatudin, Rifqi Hidayat (Sriwahyuni, 2019)	1,1881	Strong Effect	0,2717	0,6556	1,7205

Based on Table 3, there are 6 studies that have an effect size of more than 1, which can be categorized as a strong effect size. Thus, these six studies show a significant effect on improving students' mathematical literacy skills when using the problem-based learning (PBL) learning model. In addition, there are 6 other studies with effect sizes between 0.6110 and 0.8618, which can be categorized as medium effect sizes. These six studies showed a moderate effect on improving students' mathematical literacy using the problem-based learning model.

To estimate the combined effect size of all the main studies, the authors need to create an estimation model by testing the homogeneity of all the studies. Information related to the homogeneity test of all primary studies can be found in Table 4.

Table 4. Effect Size Distribution Heterogeneity

Heterogeneity				
Chi²	**Df (Q)**	**P - Value**	**I - Squared**	**Tau²**
95,00	11	P < 0,001	88 %	1,1391

From the data in Table 4, the p-value is less than 0.05, indicating that the distribution of effect sizes from the primary studies analyzed in this meta-analysis is heterogeneous. Therefore, the estimation model used to determine the combined effect size is the random effects model. Furthermore, publication bias was identified using a funnel plot, which can be seen below.

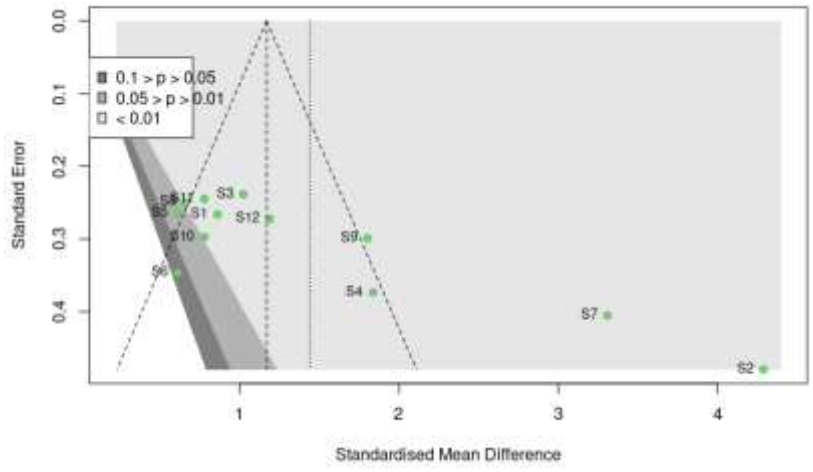


Figure 1. Funnel Plot

Based on Picture 1, it can be seen that the distribution of study effect sizes has an asymmetrical shape. This indicates the possibility of publication bias. To detect the presence of publication bias, the authors used Fail-Safe N (FSN) with a number of 918 from the total observed studies (k) of 12. By using the appropriate formula, namely $\frac{FSN}{5k+10} = \frac{918}{5(12)+1} = \frac{918}{61} = 15{,}05 > 1$, It is concluded that the studies in this meta-analysis are quite tolerant of publication bias (Tamur et al., 2020). Furthermore, the results of the meta-analysis of the primary studies using the fixed effects model and the random effects model are described in Table 5.

Table 5. Meta-Analysis Results by Estimation Model

Model	**N**	**Effect Size and 95% Confidence Interval**				**Test Of null (2 – Tail)**	
		Effect Size	**SE**	**Lower Bound**	**Upper Bound**	**Z - Value**	**P - Value**
Fixed-effects model	12	1,1702	0,1653	1,0049	1,3355	13,88	< 0,0001
Random-effects model	12	1,4404	0,7278	0,7127	2,1682	4,36	0,0011

In the previous study, a homogeneity test was conducted to identify whether the distribution of effect sizes was heterogeneous. Therefore, the analysis was conducted using the random effects model. Table 5 presents the p-value of the Z-test, which shows a value of <0.0001. With a p-value <0.05, it can be concluded that overall, the use of the PBL model has a significant effect on students' mathematical literacy skills. The combined effect size in this study was obtained as 1.4404, which is classified as a strong effect size according to Cohen's classification. Therefore, it can be concluded that the overall application of the PBL model has a strong influence on students' mathematical literacy skills. In this context, it is important to note that the distribution of the effects of the primary studies is heterogeneous, so an analysis of the study characteristics is needed to understand the heterogeneity in the use of PBL learning models on students' mathematical literacy. The meta-analysis study conducted by Paloloang et al (2020) also mentioned that the implementation of PBL has a significant positive impact on students' mathematical literacy skills compared to the conventional approach. The results of the meta-analysis showed several characteristics described in Table 6.

Table 6. Results of Meta-Analysis by Study Character

Study Character	Categorize	n	Hedges's g	Test of null (2-tail)	95% CI	
				P-Value	Lower Bound	Upper Bound
Level of education	SD	1	1,44	< 0,01	0,71	2,17
	SMP	8	1,69	< 0,01	0,57	2,80
	SMA/SMK	3	0,71	0,78	0,39	1,03
Research year	2018 - 2020	4	1,45	< 0,01	-0,51	3,41
	2021 - 2023	8	1,44	< 0,01	0,44	2,44
Sample Size	30 or less	6	1,88	< 0,01	0,24	3,51
	31 or more	6	1,03	0,06	0,62	1,44
Region	Java Island	10	1,22	< 0,01	0,45	1,99
	Outside Java Island	2	2,53	< 0,01	-7,03	12,09

Based on the grouping based on the characteristics presented in Table 6, the following information was obtained regarding the use of PBL learning models on students' mathematical literacy skills:

3.1 Characteristics based on education level

Based on the results of the analysis of education level characteristics in Table 6, there is some information that can be concluded. Of the 12 studies, one study discussed the effect of PBL implementation on mathematical literacy skills at the primary school level, eight studies discussed the effect of PBL at the junior high school level, and three studies discussed the effect of PBL at the senior high school level. Furthermore, p-values of less than 0.01 for primary and junior secondary levels indicate that both characteristics have heterogeneous effect size distributions. To visualize the effect size, it can be seen in the following boxplot diagram:

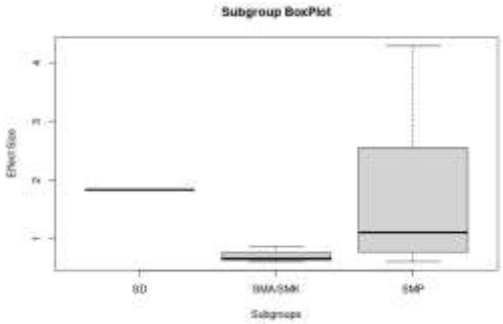


Figure 2. Boxplot by Education Level

The boxplot above shows that the application of the PBL learning model to mathematical literacy skills provides the largest effect size for junior high school students compared to primary and senior high school students. The application of PBL provides a strong effect size on mathematical literacy skills at the elementary and junior high school levels, while at the high school/vocational school level, students only provide a moderate effect size. From the diagram, it can also be seen that the study at the junior high school student level has the largest range of data; this can be seen from the size of the boxplot.

3.2 Characteristics based on research year

Based on the results of the analysis of characteristics in the research year in Table 6, it is known that there are four studies that discuss the effect of PBL implementation on students' mathematical literacy skills in the 2018–2020 research year range and eight studies that discuss the effect of PBL implementation on students' mathematical literacy skills in the 2021–2023 range from a total of 12 primary studies analyzed. The p-value for both characteristics is <0.05, which means that both characteristics are heterogeneous. As for the visualization of the effect size, it can be seen in the following boxplot diagram:

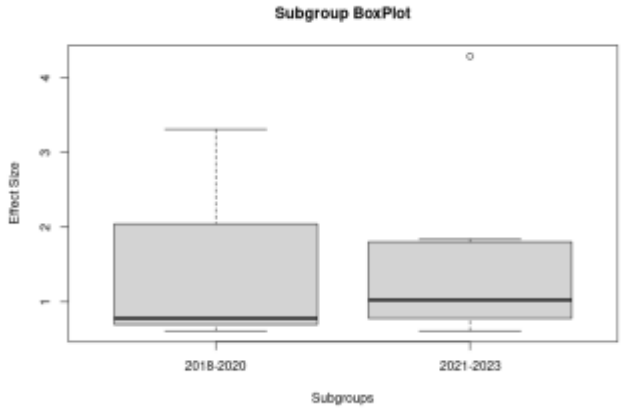


Figure 3. Boxplot by Research Year

The boxplot above shows that the application of the PBL learning model has a strong effect on students' mathematical literacy skills in both years of study, but the largest effect size is in the range of study years between 2018 and 2020. Judging from the larger size of the boxplot, it can be seen that the study in the 2018–2020 year range has the largest range of data.

3.3 Characteristics based on sample size

In Table 6, it is known that six studies discussed the effect of PBL model implementation on students' mathematical literacy skills with a research sample size of 31 students or more, and the remaining six studies discussed the effect of PBL model implementation on students' mathematical literacy skills with a sample size of 30 students or less. Furthermore, studies that have a sample size of 30 students or less have a heterogeneous effect size distribution because the p-value is <0.05. As for the visualization of the effect size, it can be seen in the following boxplot diagram

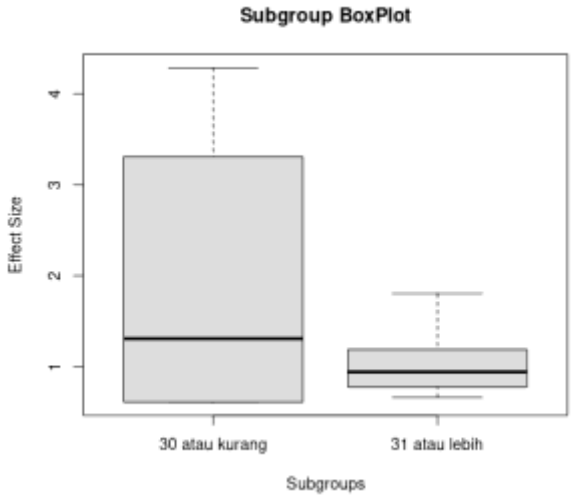
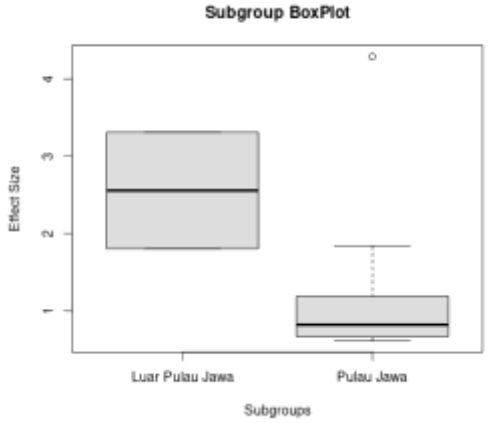


Figure 4. Boxplot by Sample Size

The boxplot above shows that the effect of PBL model implementation on students' mathematical literacy skills provides a larger effect size in studies that have a sample size of 30 students or less than the study sample size of 31 students or more, but both study characteristics have a strong effect size category.

3.4 Characteristics based on Region

A review of the characteristics of the studies analyzed in this study is based on the research area, which is divided into two, namely the island of Java and outside the island of Java. Based on Table 6, there are ten studies discussing the application of PBL learning models to students' mathematical literacy skills whose research locations are on the island of Java, while the remaining two studies are in research locations outside Java. Both regional characteristics have a heterogeneous distribution of effect size because they have a p-value <0.05. As for the visualization of the effect size, it can be seen in the following boxplot diagram:



Picture 5. Boxplot by Region

The boxplot above illustrates that the application of PBL learning to students' mathematical literacy skills provides an effect size with a strong category in two research locations, namely the island of Java and outside the island of Java. But the largest effect size is at the research location outside Java, which is 2.53. This is in line with the results of research conducted by Simamora et al., (2022) in one of the junior high schools in Medan. The researcher mentioned that with conventional learning, students' ability to solve problems is still considered very weak because students find it difficult to understand and tend to be passive in learning mathematics, while the ability to solve problems is one of the abilities needed in mathematical literacy skills. By applying the PBL learning model, it can improve students' mathematical literacy skills better than conventional learning. The next research was conducted outside Java, precisely in the West Cibal sub-district area, East Nusa Tenggara Province (NTT). This research was conducted by Kurnila et al., (2022). The results of the study stated that the application of PBL-assisted portfolios can facilitate students to optimize problem-solving skills that have an impact on improving mathematical literacy skills.

4. Conclusion and Suggestion

Based on the meta-analysis conducted on 12 primary studies that have been selected based on the inclusion criteria, it was found that the combined effect size was 1.4404, which is included in the strong effect size category according to Cohen's classification. This concludes that the application of the PBL learning model has a stronger impact on students' mathematical literacy skills compared to conventional learning. Whereas in conventional learning, the teacher acts as the center of learning, students are less involved in the learning process, and as a result, the development of students' creativity and problem-solving skills is hampered.

In addition, in terms of several study characteristics, the effect of PBL learning on students' mathematical literacy skills is influenced by the level of education, year of study, sample size, and research area. All characteristics provide a strong effect size on the study of PBL implementation on students' mathematical literacy skills, except at the SMA/SMK level, which only provides a medium effect size. But all characteristics do not provide significant differences in the impact of PBL on students' mathematical literacy skills, meaning that being able to improve students' mathematical literacy skills is not influenced by differences in education level, research year, sample size, or even the research area. The findings of this study are expected to contribute to teachers who want to apply the PBL learning model to improve students' mathematical literacy skills. However, the author also expects this study to be studied more widely.

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