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Meta-Analysis: The Effect of Discovery Learning on Mathematical Critical Thinking Skills Over 5 Years

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Abstract. *This study aims to analyse the effect of the discovery learning model on students' mathematical critical thinking skills through a meta-analysis method. This study employs a systematic review approach referring to PRISMA guidelines and involves 10 primary studies that meet the inclusion criteria within the 2021–2025 period. Data were analysed using Comprehensive Meta-Analysis (CMA) software version 4.0 by calculating the effect size and testing heterogeneity, publication bias, and sensitivity analysis. The results show that overall, the discovery learning model has a positive and significant effect on students' mathematical critical thinking skills with a combined effect size of 0.868, which is categorised as a very large effect in the random effects model. The heterogeneity test indicates high variation among studies ($Q = 109.533$; $p < 0.05$), and the random effects model was used. The moderator analysis results reveal that the most significant effect is found at the junior high school level, in Java and Sulawesi regions, and in small sample sizes. Publication bias testing using funnel plot, trim and fill, and Fail-Safe N indicates that the results are stable and free from significant publication bias.*

Keywords: *Discovery Learning, Meta-Analysis, Mathematical Critical Thinking, Mathematics Education*

INTRODUCTION

Mathematics is a discipline characterised by its abstract nature and the demand for higher-order thinking skills in the learning process. This abstract nature often causes students to experience difficulties in understanding concepts and solving mathematical problems (Alfiyah et al., 2021). In addition, mathematics has a distinctive characteristic in the form of deductive reasoning, which involves ideas, concepts, and abstract symbols arranged hierarchically (Manullang et al., 2024). Therefore, mathematics learning not only emphasises conceptual mastery but also the development of students' mathematical critical thinking skills.

Critical thinking ability is the skill to analyse information, evaluate ideas, and draw logical conclusions based on available evidence (Siswanto & Ratiningsih, 2020). In mathematics learning, mathematical critical thinking skills are very important because they help students understand concepts deeply and solve problems systematically (Fitri et al., 2023). However, various educational evaluation results indicate that Indonesian students' mathematical abilities are still relatively low.

The results of the Programme for International Student Assessment (PISA) show that the average mathematics score in 2022 decreased by 12–13 points compared to 2018, and only 18% of students reached proficiency level 2 in mathematics. The consistently low and unstable PISA performance indicates that Indonesian students' mathematical abilities are still below the international average, thus requiring innovation in learning to improve students' critical thinking skills.

One effort that can be made to improve mathematical critical thinking skills is by implementing student-centred learning models, such as discovery learning. According to Andariska et al. (2024), discovery learning is a learning model that requires students to play an active role during the learning process, enabling them to independently discover concepts in each subject studied. This model encourages students to actively find concepts through investigation and exploration, making learning more meaningful (Setyawan & Kristanti, 2021)

Various previous studies on the effect of discovery learning on mathematical critical thinking skills (Sidiq & Prasetyo, 2020; Intani et al., 2024; Pasaribu et al., 2020) indicate that discovery learning has the potential to improve students' mathematical critical thinking skills. However, these findings remain inconsistent. Some studies report that discovery learning has a significant effect with moderate to high categories (Sidiq & Prasetyo, 2020; Intani et al., 2024), while other studies show that different learning models, such as problem-based learning, are more effective than discovery learning (Pasaribu et al., 2020)

These differences in findings indicate that conclusions regarding the effect of discovery learning on mathematical critical thinking skills are still inconsistent. Therefore, research using a meta-analysis approach is needed to combine and analyse various previous studies in order to obtain more comprehensive conclusions regarding the effect of discovery learning on students' mathematical critical thinking skills (Mathew, 2022). This is important to determine the extent to which research findings show consistency or discrepancies, especially as the number of similar studies continues to increase, which often leads to differing results.

Several meta-analysis studies have examined the effect of discovery learning on mathematical critical thinking skills (Palupi & Indriani, 2024; Anjarwati et al., 2022; Suwarno et al., 2022), showing that discovery learning generally has a positive effect on students' mathematical critical thinking skills across various educational levels. However, studies that specifically analyse research within the last five years are still limited, particularly those that consider moderator variables such as educational level, sample size, and research region. Therefore, these three variables are important to be analysed to explain the heterogeneity of the effect of discovery learning on students' mathematical critical thinking skills.

RESEARCH METHOD

This study employs a systematic review approach using a meta-analysis method to synthesise a number of relevant primary studies related to the effect of implementing discovery learning on students' mathematical critical thinking skills. In its implementation, the meta-analysis is conducted through several stages: (1) formulating the research problem, (2) determining inclusion criteria, (3) developing a literature search strategy, (4) selecting studies, (5) extracting data, (6) conducting statistical analysis, and (7) interpretation and reporting. These stages are applied in this study to obtain systematic and comprehensive results.

Inclusion Criteria

This meta-analysis study needs to be limited through inclusion criteria so that the review becomes more focused and specific, resulting in a more in-depth and detailed analysis process. The determination of inclusion criteria can be carried out using the PICOS approach to screen and select relevant studies (Methley et al., 2014). Thus, the inclusion criteria used in this study are based on the PICOS approach as follows:

1. Study articles conducted at primary to secondary education levels, including elementary school, junior high school, and senior high school.
2. Study articles on the discovery learning model in the experimental class.

3. Study articles that use other learning models as the control class.
4. Study articles that employ an experimental research design (quasi-experimental).
5. Research sources derived from national journal articles indexed in Sinta, Google Scholar, Semantic Scholar, Garuda, as well as other scientific works such as undergraduate theses, master's theses, and dissertations.
6. Studies published within the last five years, namely between 2021 and 2025.
7. Primary studies reporting statistical data such as means, standard deviation, sample size, t-value, and p-value in both intervention and control groups.

Literature Search Strategy

The study selection process was conducted by searching various scientific databases to obtain articles relevant to the research topic. The databases used in the search process included Google Scholar, Semantic Scholar, Garuda, and SINTA. Primary studies were identified using the keywords "discovery learning", "critical thinking skills", "critical thinking ability", and "mathematical critical thinking". All retrieved articles were then screened based on their titles and abstracts to ensure their relevance to the research focus. Thus, the use of multiple scientific databases and appropriate keyword selection helps in identifying and obtaining primary studies that meet the inclusion criteria.

Study Selection

The implementation of this study follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, which serve as a framework to ensure that systematic review and meta-analysis reports are prepared in a transparent, comprehensive, and well-structured manner (Page et al., 2021). Figure 1 presents the PRISMA flow diagram, which briefly illustrates the study selection procedure in this research.

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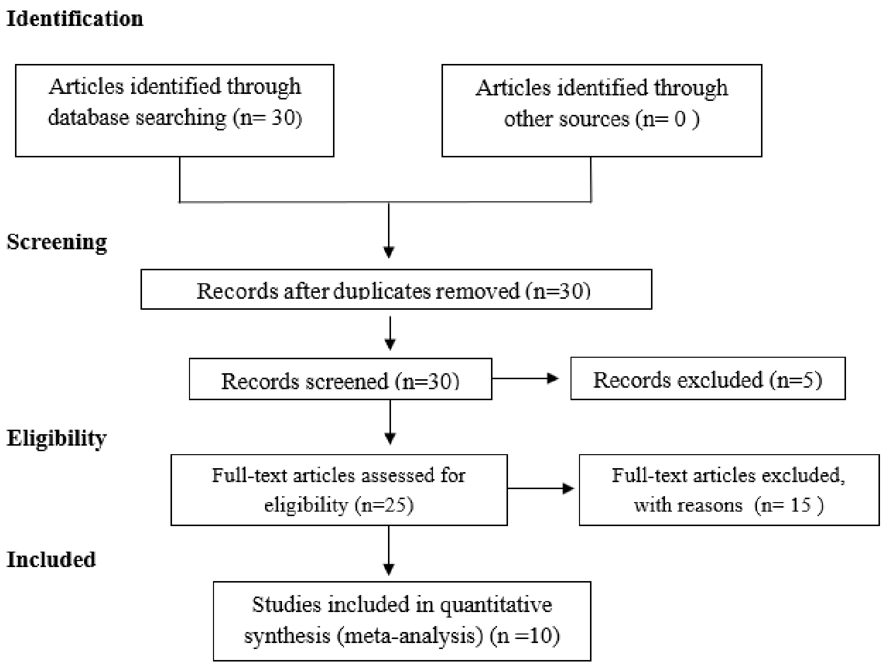

Figure 1. PRISMA Flow Diagram

Data Extraction

Primary study articles that met the inclusion criteria and passed the selection process were then subjected to a data extraction stage to obtain the information required for this study. To facilitate this process, the researchers developed a coding sheet as an instrument in this meta-analysis study. This coding sheet was used to record various important pieces of information from each study, such as research identity, education level, sample size, research region, and the required statistical data. The coding process was carried out systematically by referring to a predetermined protocol and involved two assessors (coders) who had an understanding of meta-analysis research. This was intended to enhance the validity and reliability of the data extracted from each article.

Based on the application of the established inclusion criteria, a total of 10 articles were deemed eligible for further analysis. All of these studies were obtained through searches in several databases, namely Google Scholar, Semantic Scholar, Garuda, and SINTA. Table 1 presents the results of the data extraction for the moderator variables.

Table 1. Results of Moderator Variable Data Extraction

No	Moderator Variable	Group	Study
1.	Education Level	SD/MI	6
		SMP/MTs	3
		SMA/SMK/MA	3
2.	Research Region	Java	9
		Sulawesi	1
		Sumatera	2
3.	Sample Size	≤30	6
		>30	6

Statistical Analysis

This study applies data analysis techniques using both descriptive and inferential statistics. It also employs effect size to test the research hypothesis. According to Anjaswanti et al. (2022), effect size is a fundamental component in meta-analysis, serving to indicate the extent to which one variable influences another and to describe the magnitude of the differences that occur. Data analysis in this study was conducted using the Comprehensive Meta-Analysis (CMA) software version 4.0 to assist in the analysis process. The interpretation of effect size refers to Cohen's classification (Paloloang, 2021), which is presented in Table 2.

Table 2. Effect Size (ES) Classification

Effect Size (ES)	Classification
0,20 ≤ ES < 0,50	Small Effect
0,50 ≤ ES < 0,80	Medium Effect
0,80 ≤ ES < 1,30	Large Effect
1,30 ≤ ES	Very Large Effect

Heterogeneity testing was conducted using the Q statistic and the significance value (p-value). If the p-value is < 0.05, then the null hypothesis stating that the effect sizes are homogeneous is rejected, and the analysis is continued using a random effects model. Conversely, if the p-value is > 0.05, the data are considered homogeneous, and the analysis is conducted using a fixed effects model. If a random effects model is applied, further analysis is carried out by considering moderator variables such as education level, sample size, and research region to identify sources of variation across studies.

This study also performed a publication bias test to ensure that the meta-analysis results were not distorted by publication tendencies. Publication bias may occur because studies with significant results are more likely to be published than those with non-significant results. To detect this bias, a funnel plot analysis was used. If the distribution of effect sizes in the funnel plot shows a symmetrical pattern, it can be concluded that there is no publication bias. Conversely, if the distribution is asymmetrical, further analysis is conducted using the Trim and Fill method to estimate and adjust for the number of missing studies. In addition, the Fail-Safe N (FSN) statistic was used to assess the robustness of the meta-analysis results against potential publication bias. The FSN value indicates the number of additional studies required to render the results non-significant. A study result is considered robust against publication bias if the ratio of FSN to $N/(5k + 10) > 1$, where k represents the number of analysed studies (Ramadhani et al., 2021).

RESULT AND DISCUSSION

Data Extraction Results

The results of data extraction from 10 primary studies that met the inclusion criteria were used in this analysis. Each study was analysed to obtain information related to study identity, methodological characteristics, and statistical data relevant to the calculation of effect size. The data extraction process was carried out by two coders who have expertise in systematic reviews and meta-analysis to ensure the accuracy of the results. The collected data were then organised systematically as a basis for the subsequent analysis stage, thereby supporting the overall reliability of the study findings.

Based on the data extraction process that has been conducted, Table 3 presents the results of data extraction from all primary studies as the basis for the meta-analysis to determine the effect of the discovery learning model on students' mathematical critical thinking skills.

Table 3. Results of Statistical Data Extraction of the Studies

Code	Citation	Statistical Data						t-value	p-value
		Discovery Learning			*Conventional*				
		$\overline{x}$	s	n	$\overline{x}$	s	n		
N1	Azmy & Yustitia (2023)	83,25		20	74,25		20	2,404	0,021
N2	Akbar, dkk. (2023)	73,4	7,138	27	68	5,922	28	3,387	0,001
N3	Maharani, dkk. (2024)	0,71	0,14	41	0,52	0,17	41	5,267	
N4	Nugraha, dkk. (2020)	55,63	11,639	32	35,59	16,89	32	6,529	
N5	Pasaribu, dkk. (2020)	63,3		20	77,9		21	1,77	
N6	Subiono & Wasitohadi (2020)	81		24	72		24	3,153	0,003
N7	Intani, dkk. (2024)	91		35	85		34	8,482	
N8	Putri, dkk. (2024)	93,72	2,9	36	95,67	3,64	36	2,87	0,005
N9	Utami & Giarti (2020)	77,59	11,327	54	81,74	11,129	56	2,305	0,023
N10	Situmorang, dkk. (2023)	77,64		25	49,44		25	7,898	

In the analysis stage, the effect size for each primary study was calculated to represent the magnitude of the effect reported in each study. This procedure was carried out as a basis for systematically and structurally synthesising the research findings. In addition, the effect sizes provide a clearer picture of the trend of effects observed across the analysed studies. Therefore, the results obtained can be used to support more comprehensive and relevant conclusions in line with the research objectives. The overall effect size results of each study are presented in Table 4.

With a 95% confidence level, Table 4 shows that the entire range of effect sizes lies between –1.586 and 2.199. Based on the classification, there are two negative effect sizes (n = 2), two moderate effect sizes (n = 2), three large effect sizes (n = 3), and three very large effect sizes (n = 3). Two studies (numbers 8 and 9) show negative effects, indicating that the discovery learning model is not more effective than conventional teaching methods in improving students' mathematical critical thinking skills. Table 5 presents a comparison of the meta-analysis results based on the effect models used in this analysis. The results using the fixed effects model show that the lower and upper bounds of the 95% confidence interval are 0.502 and 0.833, respectively. In addition, this study has an overall effect size of 0.668, which falls into the moderate effect category.

Table 4. Effect Size Results of Each Study

No	Author	Effect Size	Standar Error	Lower Limit	Upper Limit
1	Azmy & Yustitia (2023)	0.745	0.321	0.116	1.374
2	Akbar, dkk. (2023)	0.813	0.277	0.270	1.356
3	Maharani, dkk. (2024)	1.209	0.238	0.742	1.676
4	Nugraha, dkk. (2020)	1.365	0.275	0.826	1.904
5	Pasaribu, dkk. (2020)	0.542	0.312	-0.070	1.154
6	Subiono & Wasitohadi (2020)	0.895	0.298	0.311	1.480
7	Intani, dkk. (2024)	2.019	0.294	1.444	2.595
8	Putri, dkk. (2024)	-0.586	0.238	-1.053	-0.119
9	Utami & Giarti (2020)	-0.367	0.191	-0.741	0.007
10	Situmorang, dkk. (2023)	2.199	0.355	1.503	2.894

The next step is to conduct a heterogeneity test to determine the appropriate estimation model. Based on Table 4, the Q value of 109.533 with a p-value of 0.000 indicates that the distribution of effect sizes is heterogeneous ($p < 0.05$). This means that there is significant variation in effect sizes across studies. The I^2 value of 91.783 indicates a very high level of variation in effect sizes among the studies. This suggests that approximately 91% of the observed variation is due to differences between studies rather than sampling error. Since the I^2 value exceeds 75%, the level of heterogeneity in this study is considered very high. Therefore, the homogeneity hypothesis is rejected, and the analysis is continued using a random effects model.

Publication Bias and Sensitivity Analysis

The funnel plot diagram shows the distribution of effect size data from the 10 primary studies included in this meta-analysis. Through the funnel plot, the level of symmetry in the distribution of effect sizes can be observed as an initial indicator in evaluating the presence of publication bias. In addition, this plot provides information about the relationship between the magnitude of effect size and the level of precision of each study, thereby allowing an assessment of the consistency of the research findings. The variation in the distribution displayed in the funnel plot also reflects the level of heterogeneity among the analysed studies. The distribution of effect size data is presented in Figure 2.

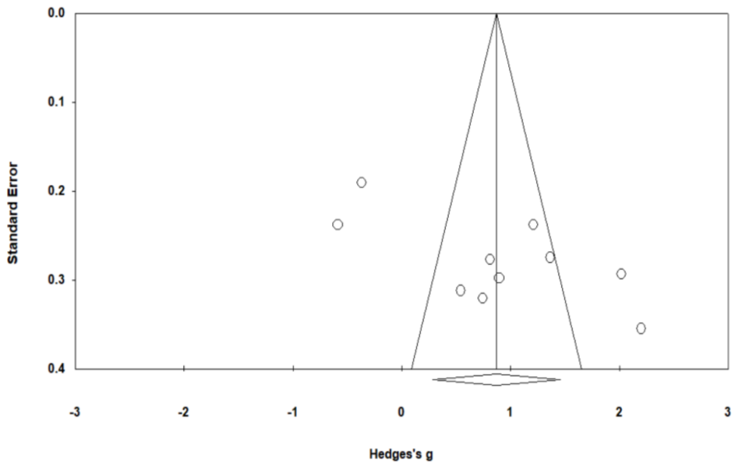

Figure 2. Funnel Plot of the Study

Figure 2 shows that the distribution of effect sizes from the 10 primary studies analysed in this meta-analysis is symmetrical. This indicates that the risk of publication bias in the effect size data is relatively low. This finding is further supported by the results of the trim and fill test, which show a balanced distribution, thereby confirming that the funnel plot is symmetrical. In addition, no effect size data needed to be added or removed from the meta-analysis process.

The Trim and Fill test is used to detect and address publication bias. Moreover, this test functions to evaluate whether there is any imbalance in the data distribution that could influence the analysis results. Based on the results obtained, an assessment can be made regarding the stability of the effect size distribution

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derived from the analysed studies. The detailed results of the Trim and Fill test are presented in Table 5.

Table 5. Trim and Fill Test Results Based on the Random Effects Model

	Trimmed Studies	Hedges'g	Lower Limit	Upper Limit	Q value
Observed Value	0	0.86797	0.28229	1.45366	109.53324
Adjusted Value		0.86797	0.28229	1.45366	109.53324

Further analysis was conducted using Rosenthal's Fail-Safe N (FSN) statistic. Based on calculations using the CMA software, an N value of 205 was obtained. When this value is substituted into the formula N/(5k + 10) > 1, the result is 205/(5 × 10 + 10) > 1, which equals 3.42 > 1. This result indicates that the findings of this study are sufficiently robust and not easily influenced by publication bias. Therefore, no studies were missing or needed to be added to the analysis due to publication bias. Table 6 below presents the detailed results of the Fail-Safe N test.

Table 6. Fail-Safe N Test Results

N Fail – Safe Klasik	
Z-Value for Observed Studies	9.08417
P-Value for Observed Studies	0.00000
Alpha	0.05000
Tails	2.00000
Z for Alpha	1.95996
Number of Observed Studies	10
Number of Missing Studies That Would Bring p-value to > Alpha	205

The next step involved conducting a sensitivity analysis using the "One Study Removed" method in the Comprehensive Meta-Analysis (CMA) software version 4.0. This method was performed by removing each study alternately from the analysis. The results show that the combined effect size remained stable after the removal of each study. This finding indicates that no single study had a significant impact on the overall conclusions. Therefore, this consistency demonstrates that the meta-analysis results are stable and reliable.

Table 7. Comparison Results Based on Estimation Models

No	Estimation Model	n	Z	p	Effect Size	Standar Error	95% CL		Q-value	p-value	I-squared
							Lower Limit	*Upper Limit*			
1	Fixed Effect	10	7.896	0.000	0.668	0.085	0.502	0.834	109.533	0.000	91.783
2	Random Effect	10	2.905	0.004	0.868	0.299	0.282	1.454			

The p-value is used as the basis for statistically testing the research hypothesis. Table 8 presents a comparison of the analysis results based on the estimation model used. In the random effects model, the 95% confidence interval ranges from 0.282 to 1.454, indicating that the estimated mean difference is likely to fall within this range. The combined effect size in the random effects model is 0.868, which can be categorised as a very large effect. In addition, the Z-test value of 2.905 with a p-value < 0.05 indicates that the result is statistically significant. Thus, it can be concluded that the implementation of the discovery learning model has a significant effect compared to conventional learning methods in improving students' mathematical critical thinking skills.

Analysis of Study Characteristics

The analysis of study characteristics is essential for identifying factors that may contribute to differences in effect sizes. Therefore, an analysis of moderator variables that may influence variations in effect sizes across studies was conducted. In this study, the moderator variables—education level, research region, and sample size—were analysed across 10 effect sizes derived from 10 primary studies to examine differences in findings among studies. The analysis process used CMA software to calculate Hedges' g value, 95% confidence intervals, Z-value, and p-value, which are presented in Table 8.

Table 8. Moderator Analysis Results

No	Moderator Variable	Group	Study	Hedges'g	Test of Null (2-Tailed)		Heterogenitas		
					Z	*P*	Q-value	Df(Q)	*P*
1	Education Level	SD/MI	4	0.498	1.397	0.163	2.083	2	0.353
		SMP/MTs	3	1.300	3.032	0.002			
		SMA/SMK/MA	3	0.926	1.139	0.255			
2	Research Region	Java	7	0.743	1.982	0.048	0.470	2	0.791
		Sulawesi	1	0.813	2.936	0.003			
		Sumatra	2	1.362	1.645	0.100			
3	Sample Size	≤30	5	1.019	3.816	0.000	0.280	1	0.597
		>30	5	0.717	1.418	0.156			

Education Level

Based on the data in Table 8, the meta-analysis results show that the effectiveness of the discovery learning model on mathematical critical thinking skills varies across education levels. At the elementary school (SD/MI) level, the Hedges' g value is 0.498 with a p-value of 0.163, indicating a small effect that is not statistically significant. At the junior high school (SMP/MTs) level, the effect size is 1.300 with a p-value of 0.002, which falls into the very large effect category and is statistically significant. Meanwhile, at the senior high school (SMA/SMK/MA) level, the effect size is 0.926 with a p-value of 0.255, which is categorised as a large effect but not statistically significant.

These findings indicate that the discovery learning model has a significant effect at the SMP/MTs level. This can be explained through constructivist theory, proposed by Jerome Bruner (Tohari & Rahman, 2024), which states that learning becomes more meaningful when students actively discover concepts through exploration and problem-solving processes. At the cognitive development stage of junior high school students, logical and analytical thinking abilities begin to develop, enabling them to follow the stages of concept discovery more independently.

This is consistent with research conducted by Pasaribu et al. (2023) and Khotimah et al. (2023), which shows that junior high school students who learn using the discovery learning model have higher mathematical critical thinking skills compared to those who use conventional learning. This finding is relevant to the cognitive characteristics of junior high school students, who are already capable of performing analysis and logical reasoning. Therefore, the implementation of discovery learning at the SMP level is effective in fostering the development of mathematical critical thinking skills through students' active involvement in the learning process.

This effectiveness is also related to the syntax of discovery learning. Students at the SMP level are generally able to respond to the stimulation and problem statement stages by analysing the given problems, then collecting and processing information during the data collection and data processing stages. These abilities enable students to perform verification and draw conclusions more logically. Thus, all stages in discovery learning contribute significantly to the development of students' critical thinking skills, as students are trained to analyse, evaluate, and synthesise information before making decisions.

Meanwhile, at the SD/MI level, students are still at the concrete operational stage, so their abstract and analytical thinking abilities have not yet developed optimally to follow the process of independently discovering concepts. On the other hand, at the SMA/SMK/MA level, the mathematics material studied tends to be more complex, so the discovery learning process requires more time, prior conceptual readiness, and more mature instructional strategies in order to have a significant effect on students' critical thinking skills.

Research Region

Based on the research region, the meta-analysis results indicate that the effectiveness of the discovery learning model on mathematical critical thinking skills varies across regions. In the Java region, the Hedges' g value is 0.743 with a p-value of 0.048, which falls into the moderate effect category and is statistically significant. In the Sulawesi region, the effect size is 0.813 with a p-value of 0.003, which is categorised as a large and significant effect. Meanwhile, in the Sumatra region, the effect size is 1.362 with a p-value of 0.100, which is classified as a very large effect but not statistically significant.

This study shows that the discovery learning model has a significant effect in Java and Sulawesi, whereas in Sumatra, although the effect size is very large, the result is not statistically significant. This may be due to considerable variation between the two studies, which increases the standard error and widens the confidence interval, ultimately leading to a non-significant result.

Differences in the effectiveness of learning models across regions can be explained through educational context theory, which states that the learning process is influenced not only by the methods or models used but also by environmental factors, the availability of learning resources, and the social and cultural characteristics of a region. This finding is supported by Lev Vygotsky's sociocultural learning theory (Tohari & Rahman, 2024), which emphasises that students' cognitive development is influenced by social interaction and the learning environment. This indicates that the educational environment in a region can affect how students understand and construct knowledge through the learning process.

This is also supported by several studies showing improvements in educational quality in Java and Sulawesi. Research by Sumarni et al. (2021) indicates that improvements in educational quality in South Sulawesi are influenced by teacher competence, school work culture, and the availability of adequate educational facilities and infrastructure. Meanwhile, research by Priatna (2018) explains that improvements in educational quality in the Java region can be achieved through the implementation of national education standards, strengthening school management, and enhancing the quality of the teaching and learning process by teachers. These conditions suggest that a supportive educational environment can enhance the effectiveness of the discovery learning model in improving students' mathematical critical thinking skills.

Sample Size

Based on sample size, the meta-analysis results indicate that the effectiveness of the discovery learning model on mathematical critical thinking skills differs between groups with sample sizes less than or equal to 30 and those with more than

30. In studies with sample sizes less than or equal to 30, the Hedges' g value is 0.941, which falls into the large effect category, with a p-value of 0.078, indicating that it is not statistically significant. Meanwhile, in studies with sample sizes greater than 30, the effect size is 0.641, which is categorised as a moderate effect, with a p-value of 0.021, indicating a statistically significant result.

This study shows that the discovery learning model is effective in both sample size groups, but it tends to have a stronger impact in groups with smaller sample sizes. This suggests that sample size, or the number of students in a class, influences the level of effectiveness of the learning model implementation. In groups with smaller sample sizes, interactions between teachers and students, as well as among students, can occur more intensively and in a more focused manner.

This finding is supported by Vygotsky's theory (Tohari & Rahman, 2024), which states that learning becomes more effective when teachers provide assistance or scaffolding within the Zone of Proximal Development (ZPD). In classes with fewer students, teachers can more easily provide individualised guidance according to students' needs. This condition allows the discovery learning process to occur more optimally, as students receive appropriate support in understanding and discovering concepts independently.

This is also supported by several studies. (Blatchford et al., 2011) state that smaller class sizes provide greater opportunities for students to actively engage in discussions, ask questions, and explore concepts. This situation supports the discovery learning approach, as students have more freedom to discover concepts independently with teacher support. (Febrianti et al., 2025) also found that learning in small groups provides more space for students to discuss, express ideas, and develop conceptual understanding collaboratively. With a more limited number of students, the interaction process and student engagement in learning become more optimal.

CONCLUSION

Based on the results of the meta-analysis of 10 primary studies, it can be concluded that the discovery learning model has a positive and significant effect on students' mathematical critical thinking skills. This is indicated by the combined effect size value of 0.868, which falls into the very large effect category under the random effects model. The heterogeneity test results show high variation among studies, indicating that the use of the random effects model is appropriate for estimating the overall effect size.

The moderator analysis shows that the effectiveness of discovery learning varies based on education level, research region, and sample size. The most significant effects were found at the junior high school (SMP/MTs) level, in the Java and Sulawesi regions, and in groups with certain sample sizes. In addition, the results of publication bias tests using funnel plots, trim and fill, and Fail-Safe N indicate that the findings are stable and not significantly affected by publication bias.

Thus, discovery learning can be considered an effective learning model for improving students' mathematical critical thinking skills, although its level of effectiveness is influenced by different study characteristics.

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