Reforma: Jurnal Pendidikan dan Pembelajaran
Faculty of Teacher Training and Education
Universitas Islam Lamongan
https://jurnalpendidikan.unisla.ac.id/index.php/reforma

November, 2025 Vol. 15, No. 2
e-ISSN: 2621-4172
p-ISSN: 2503-1228
pp. 124-140

A Meta-Analysis of Project-Based Learning's Effect on Mathematical Communication Skills Across Educational Levels and Group Sizes

[1]Abdur Rahman Hakim, [2]Hasanuddin, [3]Firza Mufti Aulia, [4]Jung Won Lee

[1,2,3]Mathematics Education, Faculty of Education and Teacher Training, State Islamic University of Sultan Syarif Kasim Riau. Jl. HR Soebrantas No. 155 Km. 15, Simpang Baru, Panam, Pekanbaru, Indonesia. Postal code: 28193
[4]Mechanical and Electrical Engineering, Kongju National University. 1223-24, Cheonan-daero, Seobuk-gu, Cheonan-si, Chungcheongnam-do, Republic of Korea. Postal code: 31080

*Corresponding Author e-mail: hasanuddin@uin-suska.ac.id

Received: 31 May 2025; Revised: 17 June 2025; Accepted: 04 Juli 2025; Published: 30 November 2025

Abstract

Mathematical Communication Skills (MCS) play a vital role in helping students structure their thinking and express mathematical ideas clearly and logically. Unfortunately, this skill remains relatively low due to limited interaction during instruction and the dominance of teacher-centered learning models. One innovative approach believed to address this issue is Project-Based Learning (PjBL), which positions students as active agents in the learning process. Numerous studies have indicated that PjBL can enhance MCS; however, it remains unclear which educational level and group size are most optimal for its implementation. This study aims to analyze the overall effect of PjBL on students' MCS, as well as its impact across educational levels and sample sizes. A meta-analysis was conducted on eight published articles selected using PRISMA guidelines and analyzed using the Comprehensive Meta-Analysis (CMA) software. Effect sizes were calculated using Hedge's g to measure the magnitude of the difference between the experimental and control groups. The results revealed that PjBL had a significant and moderately (0,785) effective impact on MCS, with students taught through PjBL demonstrating an average of 78.38% higher MCS compared to those in conventional learning environments. The highest effectiveness was found at the junior high school level, which aligns with Piaget's view that students at this stage are in the concrete operational stage and are more responsive to activity-based and collaborative learning. Furthermore, PjBL was more effective when applied in smaller group sizes, as it allowed for more intensive interaction and support. However, the limited number and diversity of studies analyzed indicate a need for further research with broader coverage and more in-depth moderator analysis to obtain a more comprehensive understanding.

Keywords: Effect Size; Hedge's g; Mathematical Communication Skills; Meta-analysis; Preferred; Project-Based Learning.

How to Cite: Hakim, A. R., Hasanuddin, A., Aulia, F. M., & Lee, J. W. (2025). A Meta-Analysis of Project-Based Learning's Effect on Mathematical Communication Skills Across Educational Levels and Group Sizes. *Reforma: Jurnal Pendidikan dan Pembelajaran, 15(2), 124-140.* ***https://doi.org/10.30736/reforma.v15i2.1250***

https://doi.org/10.30736/reforma.v15i2.1250

Copyright© 2025, Hakim et al
This is an open-access article under the CC-BY-SA License.

INTRODUCTION

Mathematical Communication Skills (MCS) are essential competencies that every student must possess, as they support success in learning mathematics. MCS encompasses the ability to convey and comprehend mathematical ideas, both orally

and in writing, through various representations such as visuals, tables, diagrams, formulas, or demonstrations (Giovanti et al., 2023). With this skill, students can organize their thinking logically and articulate mathematical concepts clearly throughout the learning process (Sudianto & Yaqin, 2024).

In addition to helping students express their thoughts, MCS also fosters deeper conceptual understanding. (Na'im & Mukhlis, 2024) state that MCS is one of the five fundamental skills according to the NCTM, as it assists students in recognizing and correcting misconceptions. Students with weak communication skills often struggle to explain their ideas, even when their answers are correct, making it difficult for teachers to provide appropriate guidance. (Wilkinson et al., 2018) further emphasize that mathematical understanding is constructed through communication, whether through language, symsbols, or images. When students actively engage in discussions and problem-solving, they learn to construct reasoning and explain steps sequentially. Therefore, MCS not only helps students convey answers but also plays a critical role in thinking processes, understanding, and solving mathematical problems.

Given this rationale, the development of students' MCS is vital and should be prioritized across all educational levels. However, field observations indicate that students' MCS levels remain relatively low. For example, in Cimahi, junior high school students scored an average of only 40 out of 100 (Lismayanti et al., 2024), while in Baubau, the average score reached 46 out of 100 (Jais et al., 2024). These data show that many students still struggle with MCS, and the average scores have not yet met the minimum competency standards.

The low level of students' MCS can be attributed to several complex factors, one of which is the learning process itself. Students tend to work on problems individually without being given opportunities to communicate their work, either individually or in groups (Lismayanti et al., 2024). Furthermore, the teaching method used also influences students' MCS (Jais et al., 2024). When teacher-centered approaches dominate the classroom, students become passive recipients of information, with minimal engagement. As a result, the focus of learning shifts away from the students themselves. Thus, there is a pressing need for innovative learning models that are student-centered and capable of fostering active engagement in the learning process (Mulyawati et al., 2018).

One such student-centered model is Project-Based Learning (PjBL). PjBL is a project-based instructional approach that encourages students to engage in discussions, think critically, and communicate their ideas effectively (Jais et al., 2024). According to Susilawati, PjBL provides more meaningful learning experiences by involving students in exploration, problem-solving, and the creation of projects relevant to real-life contexts (Apriani et al., 2024). Through this approach, PjBL is considered a promising strategy to improve students' MCS (Lubis et al., 2024).

Various studies have demonstrated that the PjBL model can enhance students' MCS. A study involving 35 senior high school students revealed that those taught using PjBL performed better in MCS compared to 34 students who were taught using conventional methods (Giovanti et al., 2023). Similar findings were reported in another study, where 38 junior high school students under the PjBL model showed higher MCS than 38 students in traditional classrooms (Ambarwati et al., 2015). Additionally, research on 35 university students also showed that those engaged in

PjBL had better MCS than those in the control group using conventional approaches (Ruqoyyah et al., 2020).

Based on the available evidence, it can be concluded that PjBL has a positive impact on students' MCS across various educational levels. However, certain gaps remain. Specifically, it is still unclear which educational level benefits the most from the application of PjBL in improving MCS. Additionally, there is insufficient information about the ideal group size for PjBL to maximize its effectiveness on MCS. Thus, a more in-depth analytical approach is needed to determine the extent of PjBL's effectiveness in enhancing MCS while accounting for these variables.

A suitable method to address this gap is meta-analysis. Meta-analysis is a technique that synthesizes the results of previous studies, interpreting and summarizing them through effect size calculations (Sukmawati, 2020). The effect size refers to the magnitude of the difference between control and experimental groups, calculated using specific statistical techniques. This method requires a large number of relevant studies to ensure strong, accurate, and generalizable results. Using this approach, the influence of the Project-Based Learning model on improving students' MCS can be assessed more objectively and comprehensively (Kufa & Susilowaty, 2022).

Given the background and urgency described above, this study aims to describe the general impact of PjBL on students' MCS and to analyze its effect based on educational level and sample size. The results of this study are expected to make a meaningful contribution to the development of mathematics education, particularly in enhancing students' MCS through the implementation of PjBL. The findings from this meta-analysis may serve as a reference for educators and policymakers in selecting instructional strategies that foster active mathematical communication, critical thinking, and deep student engagement. In doing so, this study aspires to support more meaningful, interactive, and quality-oriented mathematics education across educational levels.

METHOD

Research Design

This study employed a meta-analysis method, a statistical technique used to process and interpret the results of previous studies (Mahmudah, 2020). Meta-analysis was selected because it allows for the synthesis of quantitative outcomes from multiple studies while calculating the pooled effect size, thereby enhancing statistical power and precision of estimates (Hansford & Schechter, 2023). Unlike a systematic review, which is primarily descriptive, meta-analysis enables the evaluation of between-study variation (heterogeneity) and detection of potential bias in individual studies. This makes it a more appropriate approach for assessing the overall impact of PjBL on students' MCS with greater validity. According to Borenstein, the meta-analysis procedure involves several stages: determining inclusion criteria, collecting and coding variable data, and conducting statistical analysis (Paloloang et al., 2021).

Inclusion and Exclusion Criteria

The population of this study comprised articles published in national-level educational journals or conference proceedings. The sample was selected based on predetermined inclusion and exclusion criteria, as presented below:

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
1. Quantitative experimental or quasi-experimental studies examining the effect of PjBL on MCS. 2. Study subjects include junior high school, senior high school, or university students. 3. Articles provide complete statistical data (mean, standard deviation, and sample size) for both experimental and control groups. 4. Written in Bahasa Indonesia. 5. Published in peer-reviewed national academic journals or educational conference proceedings. 6. Published between 2014 and 2024.	1. Articles in foreign languages other than Bahasa Indonesia (e.g., English articles without Indonesian contextual relevance). 2. Subjects not aligned with the study focus (e.g., early childhood, teachers, or elementary students). 3. Non-quantitative studies (e.g., descriptive, literature review, qualitative). 4. Inappropriate publication types (e.g., theses, dissertations, blogs). 5. Articles lacking complete statistical data. 6. Articles unavailable in full text or inaccessible.

Data Collection

Data were gathered through the Harzing's Publish or Perish platform connected to Google Scholar using the keywords "Model Project-Based Learning"(Project-Based Learning Model) and "kemampuan komunikasi matematis" (mathematical communication skills), which represent the main study variables. Only articles written in Bahasa Indonesia were included to ensure contextual relevance and readability. Google Scholar was chosen due to its broad literature coverage, while Harzing's software facilitated efficient data extraction. The search results were screened using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure that selected studies were directly relevant to the topic. PRISMA involves four steps: Identification, Screening, Eligibility, and Inclusion (Ramadhan & Zaidal, 2024). These steps are illustrated in Figure 1 (Haddaway et al., 2022).

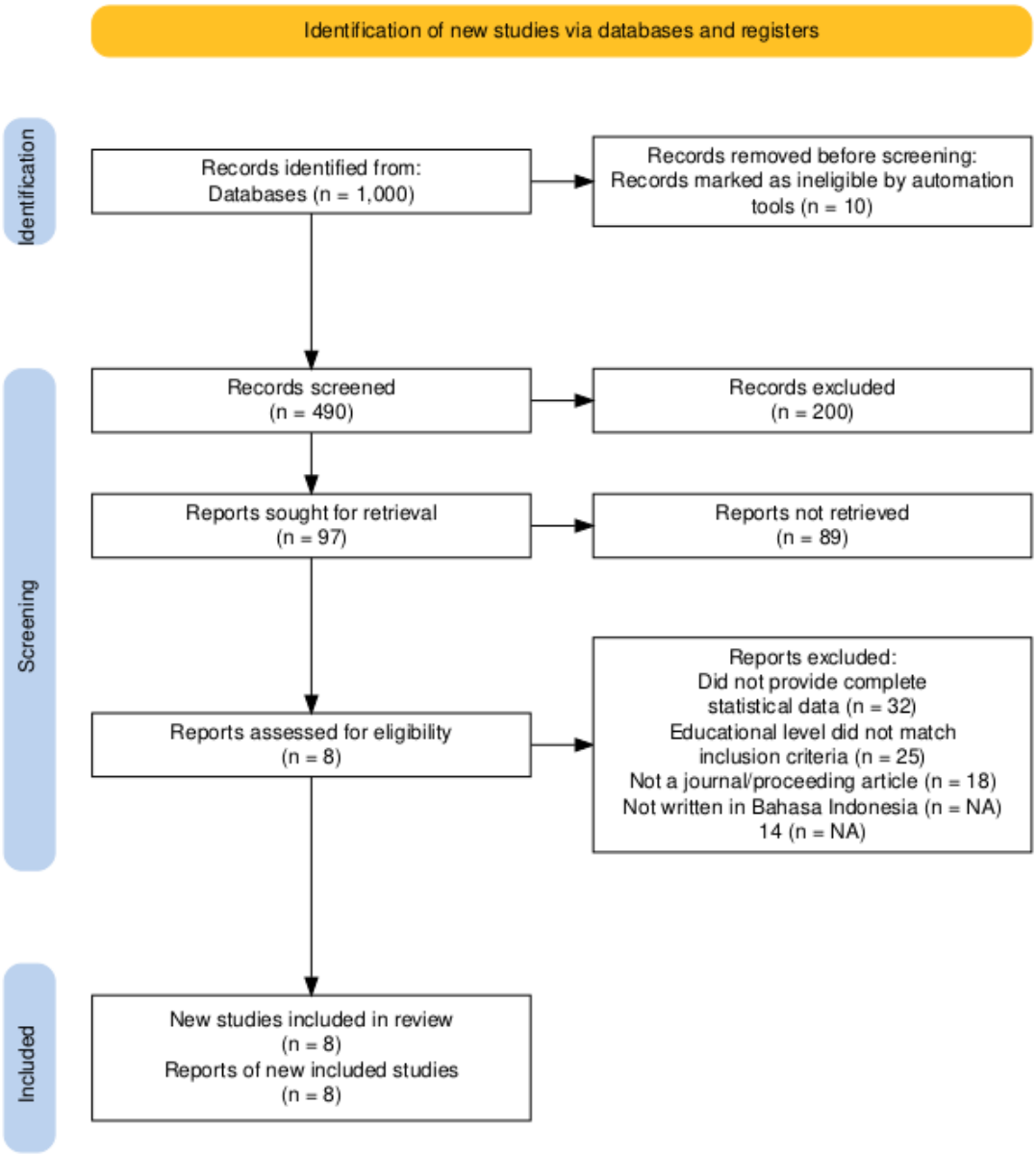


Figure 1. PRISMA Flowchart

Out of 1,000 identified articles, 10 were automatically excluded due to basic disqualification such as duplication or irrelevance. Then, 490 articles were screened based on titles and abstracts, with 200 being excluded for not addressing PjBL or MCS. The remaining 97 full-text articles were assessed, from which 89 were eliminated due to lack of access or incomplete statistical data. In the end, eight articles met all criteria and were included in the meta-analysis.

The common reasons for article exclusion at earlier stages included incomplete statistical reporting (n = 32), unsuitable educational levels (n = 25), non-peer-reviewed sources (n = 18), and non-Indonesian language (n = 14). All included articles were evaluated for quality based on three indicators: clarity of experimental design, statistical reporting, and consistency between research objectives and conclusions. Only studies of moderate to high quality were retained. General information about the selected studies is presented in Table 2.

Table 2. Profile Information of Selected Articles

Researcher Name	Code	Journal/proceedings
(Lismayanti et al., 2024)	PjBL 1	JPMI: Jurnal Pembelajaran Matematika Inovatif Vol. 07 No. 06, 2024. Hal: 30-40,
(Ruqoyyah et al., 2020)	PjBL 2	Jurnal Ilmiah P2M STKIP Siliwangi Vol. 07 No. 02, 2020, Hal: 126-133.
(Jais et al., 2024)	PjBL 3	Jurnal Akademik Pendidikan Matematika Vol. 10 No. 01, 2024. Hal: 32-36.
(Ambarwati et al., 2015)	PjBL 4	UJME: Unnes Journal of Mathematics Education Vol. 04 No. 02, 2015. Hal: 180-186.
(Lubis et al., 2024)	PjBL 5	Jurnal on Education Vol. 06 No. 02, 2024. Hal: 14842-14850,
(Chalim et al., 2019)	PjBL 6	PRISMA: Prosiding Seminar Nasional Matematika 2, Hal: 540-550,
(Mulyawati et al., 2018)	PjBL 7	Jurnal Penelitian Pendidikan Matematika Hal: 1-9.
(Andriani et al., 2023)	PjBL 8	Jurnal Inovasi Pendidikan dan Sains Vol. 04 No. 02, 2023. Hal: 102-107.

Table 3. Article Information Based on Moderator Variables

Moderator Variable	Group	Frequency
Educational Level	University (U)	1
	Senior High School (SHS)	5
	Junior High School (JHS)	2
Sample Size	≤ 30 participants	3
	≥ 31 participants	5

Data Coding

A variable coding sheet was developed as the main instrument to facilitate data collection and analysis while ensuring that no essential information was missed. The sheet, created using Microsoft Excel, systematically organizes each study as a row and includes coded variables such as author name, publication year, educational level (junior high school, senior high school, university), sample size group (≤30 or ≥31), and source type (journal or proceeding). It also includes descriptive and quantitative data: means (Xe), standard deviations (Se), and sample sizes (Ne) for the experimental group, as well as corresponding values (Xc, Sc, Nc) for the control group.

The coding was conducted manually and independently by two researchers. Any discrepancies were resolved through discussion until consensus was achieved. Inter-coder reliability was assessed using Cohen's Kappa, yielding $\kappa = 0{,}89$, indicating a very high level of agreement. Although the sheet had a fixed structure, it remained semi-flexible to accommodate format differences across studies. For instance, if the educational level or sample size was not explicitly stated in a table but described narratively in the methods or background, it was interpreted accordingly. A pilot coding test was conducted on two studies to ensure all categories were consistently applied before the main analysis. Any studies lacking verifiable statistical data were excluded. The full coding structure is shown in Table 4.

Tabel 4. Data Coding Sheet

Study Name	Year	Education Level	Group Sample	Source Type	Experimental Group			Control Group		
					Xe	Se	Ne	Xc	Sc	Nc
PjBL 1	2024	JHS	31	Journal	82,3	4,65	30	77,8	6,15	30
PjBL 2	2020	U	31	Journal	79,75	0,3	35	76,25	0,39	35
PjBL 3	2018	JHS	30	Journal	74,55	10,791	22	66,59	14,09	22
PjBL 4	2022	JHS	30	Journal	32,8	2,6	15	21,2	4,4	11
PjBL 5	2024	SHS	31	Journal	62	16,12	36	53	25,11	35
PjBL 6	2019	SHS	31	proceeding	82	6,37	36	79	6,51	35
PjBL 7	2019	JHS	31	Journal	82,619	11,875	81	69,545	14,819	80
PjBL 8	2022	JHS	30	Journal	86,85	10,436	21	77,95	11.944	22

Statistical Analysis

According to Borenstein, the statistical analysis process in a meta-analysis consists of several key stages: (1) calculating the effect size, (2) testing heterogeneity to determine the most appropriate estimation model, (3) assessing potential publication bias using funnel plots and Fail-Safe N (FSN) testing, and (4) conducting hypothesis testing based on the resulting p-values (Sari et al., 2021).

The data analysis in this meta-analysis was conducted using the Comprehensive Meta-Analysis (CMA) software. The effect size was calculated using Hedge's g, which is particularly suitable for studies with small to moderate sample sizes. Hedge's g is preferred because it includes a correction for potential bias due to small sample sizes and is widely recommended in educational meta-analyses. The interpretation of effect size magnitude follows the guideline proposed by Cohen et al., which categorizes the effect as follows: an effect size below 0,20 is considered very small, 0,20 to <0,50 is small, 0,50 to <0,80 is moderate, 0,80 to <1,30 is large, and ≥1,30 is very large (Sari et al., 2021).

To determine the appropriate statistical model (fixed-effect or random-effects), a heterogeneity test was conducted using the Q statistic, I^2 value, and p-value. The Q statistic evaluates whether the variation between studies exceeds what would be expected due to random error alone. If the p-value of the Q test is less than 0,05, the heterogeneity is considered statistically significant. The I^2 value represents the percentage of total variation across studies due to true heterogeneity rather than chance. If significant heterogeneity is detected (Q significant and I^2 large), a random-effects model is applied, as it accommodates differences in study characteristics. Conversely, if heterogeneity is low or non-significant, a fixed-effect model is used.

To address potential distortion caused by outliers, a sensitivity analysis was performed to examine whether studies with extreme effect sizes had a significant influence on the overall pooled effect. Studies with unusually high or low effect sizes were analyzed separately to assess whether excluding them would alter the general conclusion.

In addition, potential publication bias was assessed using two approaches: (1) a funnel plot, as a visual tool to determine whether studies are symmetrically distributed around the pooled effect size, and (2) the Fail-Safe N (FSN) calculation, which estimates the number of null-result studies required to nullify the observed

significant result of the meta-analysis. If the ratio of FSN to (5K + 10) exceeds 1 (with K being the number of included studies), the meta-analysis is considered robust against publication bias (Sari et al., 2021).

To better understand the stages of the meta-analysis method used in this study, the following diagram illustrates each step of the meta-analytic process.

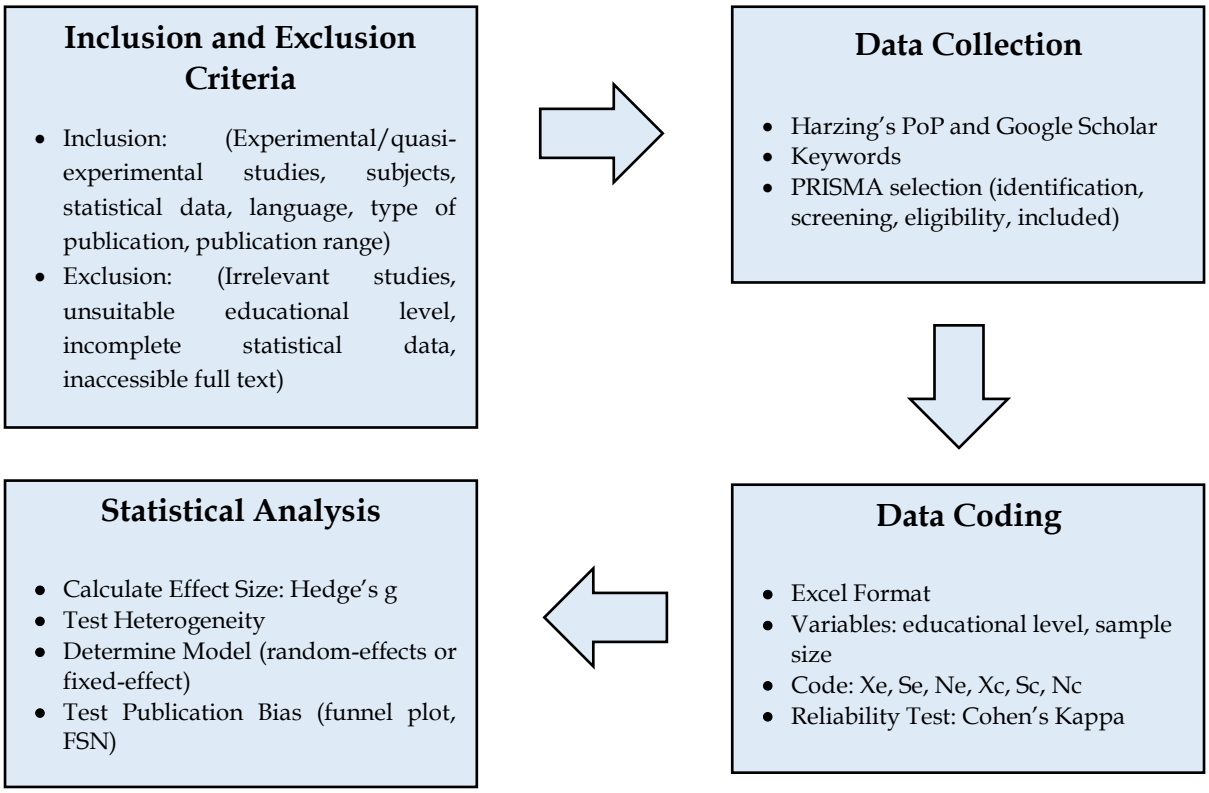


Figure 2. Stages of the Meta-Analysis Method in This Study

RESULTS AND DISCUSSION

Results

Phase One: Individual Study Effect Sizes

The initial step in the analysis involved calculating the individual effect sizes for each study, as summarized in Table 5.

Table 5. Transformed Effect Sizes of Included Studies

No	Code	Effect Sice	Category
1	PjBL 1	0,815	Large
2	PjBL 2	0,398	Small
3	PjBL 3	0,623	Moderate
4	PjBL 4	2,991	Very Large
5	PjBL 5	0,423	Small
6	PjBL 6	0,461	Small
7	PjBL 7	0,970	Large
8	PjBL 8	0,776	Moderate
Prediction Interval		0,785	Moderate

The data show that effect sizes from the eight studies ranged from 0,398 to 2,991 with a 95% confidence level. Based on Cohen's classification, one study reported a very large effect, two reported large effects, three had moderate effects, and two reported small effects. The most extreme value was observed in study PjBL 4 (g = 2,991). However, sensitivity testing showed that even after accounting for this outlier, the overall effect remained in the moderate category and stable, indicating that this extreme value did not significantly bias the overall conclusion.

The distribution of effect sizes and confidence intervals is visualized in the forest plot below.

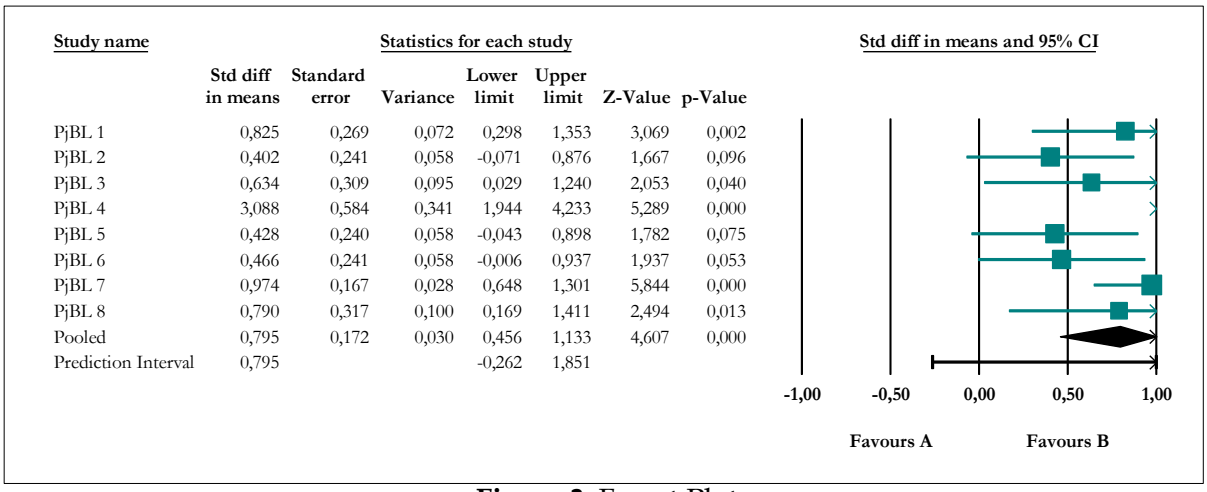


Figure 3. Forest Plot

The forest plot illustrates the effect sizes of the eight studies on the implementation of Project-Based Learning (PjBL). Each horizontal line represents the 95% confidence interval of a study, while each square indicates the standardized effect size (Hedge's g). Most studies show positive results, with effect sizes located to the right of the central axis (Favours B), indicating support for the effectiveness of PjBL over conventional methods (Favours A).

Phase Two: Heterogeneity Testing

Before selecting the appropriate estimation model for the meta-analysis, heterogeneity testing was conducted to assess the consistency of results across studies. The test considered three indicators: Qb value, p-value, and I^2. The results are shown in Table 6.

Table 6. Model Estimation and Heterogeneity Results

No	Estimation Model	n	Z	p	Q_b	P-value	I-squared
1	Fixed-Effects	8	8,275	0,000	23,199	0,002	69,826
2	Random-Effects	8	4,624	0,000			

The Qb value of 23.199 with p = 0,002 indicates significant heterogeneity among the analyzed studies. The I^2 value of 69,83% suggests that nearly 70% of the variance across studies was due to actual heterogeneity rather than chance. Based on common interpretation guidelines, this level of I^2 indicates moderate to high heterogeneity, implying substantial contextual or methodological differences among the studies.

Due to this significant heterogeneity, the **random-effects model** was selected for the primary analysis. This model is more appropriate when combining studies from diverse contexts, including varying educational levels and sample sizes. The random-effects model also showed statistically significant results (Z = 4,624; p < 0,001), confirming the consistency of PjBL's impact despite variation across studies.

Phase Three: Publication Bias Testing

To assess potential publication bias, a funnel plot was generated and is shown below:

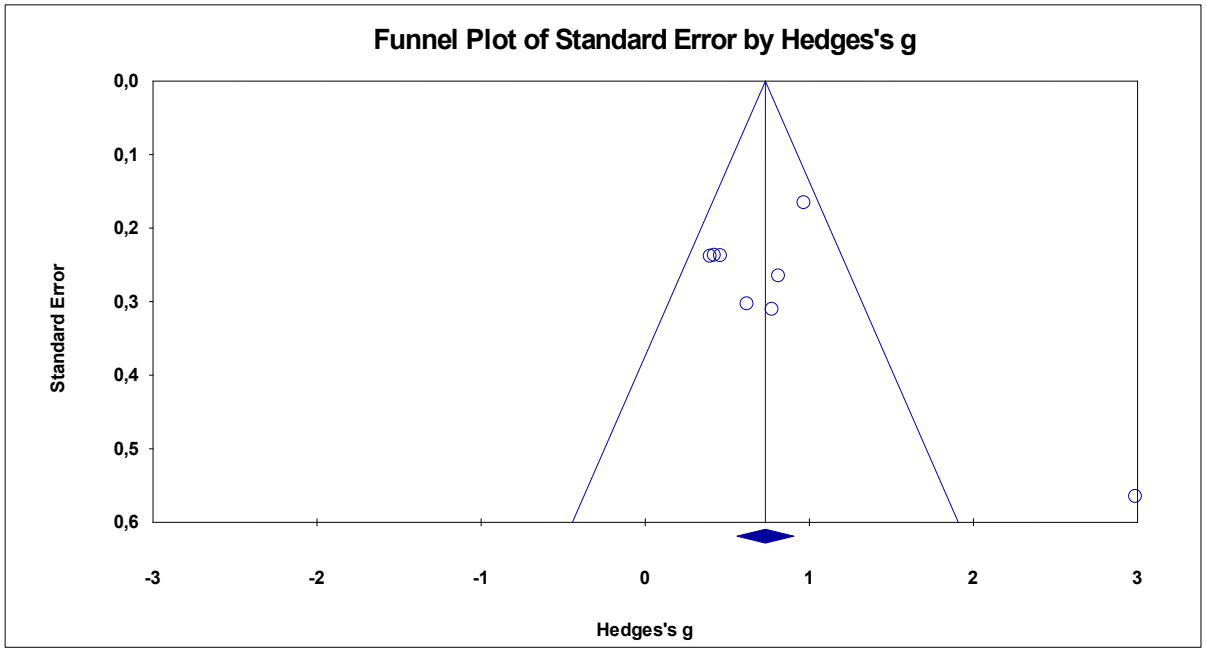


Figure 4. Funnel Plot of the Study

The funnel plot shows that most studies are symmetrically distributed around the pooled effect size line, with most data points falling within the expected range. This indicates no systematic publication bias. Although one study appears on the far right, this likely reflects a high effect size due to unique contextual or design factors rather than reporting bias.

A Fail-Safe N (FSN) analysis using Rosenthal's method also supported this finding. The CMA software computed an FSN of 144. When applying the formula FSN 144/ (5K + 10), where K is the number of studies (8), the resulting value is 2,28. Since this exceeds the threshold of 1, it can be concluded that the results of the meta-analysis are robust against publication bias. Nevertheless, Rosenthal's method has limitations, such as not accounting for the quality of missing studies, which may still result in overestimated FSNs. Thus, FSN should be interpreted as supporting evidence rather than conclusive proof.

Phase Four: Hypothesis Testing

The fourth stage involved hypothesis testing using p-values, with results presented in Table 7 (random-effects model).

Table 7. Hypothesis Test – Random-Effects Model

n	Z	p	Effect Size	Standard Error	95% CL Lower Limit	95% CL Upper Limit
8	4,624	0,000	0,785	0,170	0,452	1,117

The analysis shows that the overall effect size is 0,785, classified as moderate to large. This means that, on average, PjBL has a substantial impact on enhancing students' mathematical communication skills compared to conventional instruction. The Z value of 4.624 and $p < 0,001$ indicate that the results are statistically significant, with a low probability that the observed effect occurred by chance. The 95% confidence interval (0,452 to 1,117) reinforces confidence in the reliability of the effect size, as it does not include zero. However, the relatively wide confidence interval suggests variation across studies, likely due to differences in educational level, sample size, or the way PjBL was implemented. Thus, while the statistical results confirm the effectiveness of PjBL, the practical significance of the findings must also be interpreted carefully in light of specific classroom contexts.

Moderator Analysis

To further examine between-study variation, a moderator analysis was conducted using two main variables: educational level and sample size. The results are presented in Table 8.

Table 8. Summary of Moderator Analysis Results

Moderator Variable	Group	n	Effect Size	Z	p	Between-Classes Effect (Q_b)	Df (Q)	P
Educational Level	U	1	0,398	1,667	0,096	8,414	2	0,015
	SHS	5	0,442	2,629	0,009			
	JHS	2	0,948	8,198	0,000			
Sample Size	≤ 30	3	0,992	4,894	0,000	2,032	1	0,154
	> 30	5	0,671	6,824	0,000			

The analysis involved three educational level categories: university (n = 1), senior high school (n = 5), and junior high school (n = 2). Results show that the highest effect size was observed at the junior high school level ($g = 0,948$; $Z = 8,198$; $p < 0,001$), followed by senior high school ($g = 0,442$; $Z = 2,629$; $p = 0,009$), with the lowest effect size found at the university level ($g = 0,398$; $Z = 1,667$; $p = 0,096$). The differences between these groups were statistically significant, as indicated by a Q-between value (Qb) of 8.414 and $p = 0,015$.

For the sample size moderator, studies were classified into two groups: those with 30 or fewer participants (n = 3) and those with 31 or more participants (n = 5). The results indicate that studies with smaller sample sizes had higher effect sizes ($g = 0,992$; $Z = 4,894$; $p < 0,001$) compared to larger sample size groups ($g = 0,671$; $Z = 6,824$; $p < 0,001$). However, the difference between the subgroups was not statistically significant, with a Qb of 2,032 and $p = 0,154$.

To further illustrate these findings, a bar chart was constructed to depict the effect sizes of each moderator group.

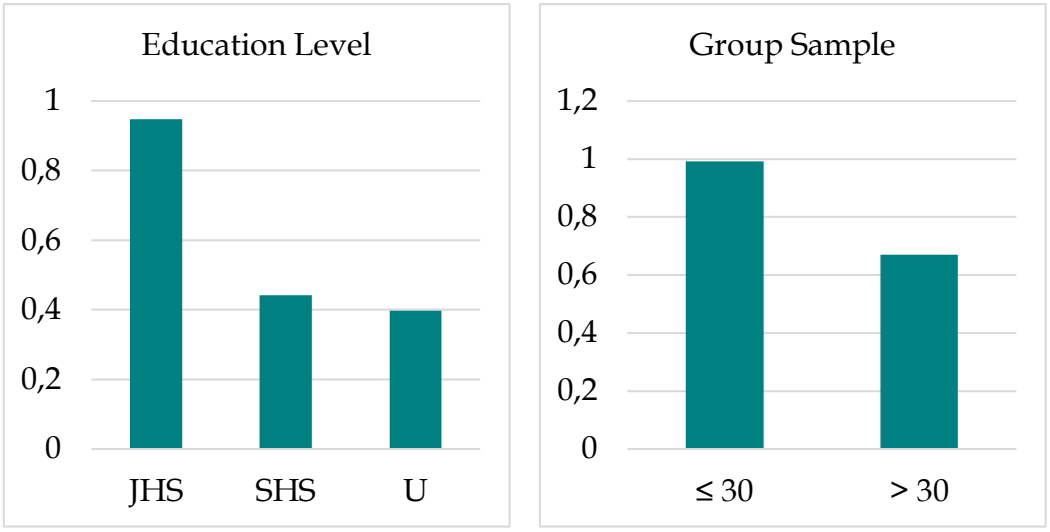


Figure 5. Bar Chart of Effect Sizes for Each Moderator

Discussion

The results of this study reveal that the implementation of Project-Based Learning (PjBL) has a statistically significant and moderately strong effect on students' Mathematical Communication Skills (MCS), with an overall effect size of 0,785. This value indicates that, on average, students taught using PjBL demonstrate MCS that is 78.38% higher than students taught using conventional methods, assuming equal initial ability. In terms of ability distribution, PjBL shifts the students' performance within the class; for example, a student who would have ranked at the 50th percentile in the control group may move to around the 78th percentile in the experimental group using PjBL. According to the learning effect interpretation by Coe et al. (Paloloang et al., 2021), this means a student who was previously ranked 14th in the control class could move up to 5th or 6th place in the experimental class.

Nevertheless, this study found that the influence of PjBL is categorized as moderate, which differs from several earlier studies that reported a very large impact of PjBL on MCS (Sihombing & Susilowaty, 2023). This discrepancy can be attributed to differences in study scope. While previous research often examined various mathematical skills broadly, this meta-analysis specifically focused on MCS. Variations in the indicators used and in the implementation context of PjBL may affect the reported effect sizes. For example, (Susilowaty, 2023) reported a moderate effect, while (Widyastuti et al., 2024) reported a very large effect. Such inconsistencies suggest that meta-analysis results must be interpreted cautiously, considering the specific context of each study.

In terms of educational level, the highest effectiveness of PjBL was found at the junior high school level, with an effect size of 0,948. This value exceeds those found in senior high school (0,442) and university (0,398). These findings are consistent with studies by (Syarifah et al., 2021) and (Susilowaty, 2023), which found that PjBL had a greater impact on mathematical abilities at lower educational levels. However, contrasting results were reported by (Sihombing & Susilowaty, 2023), who found that PjBL had stronger effects on certain mathematical skills at higher education levels. This variation suggests that the effectiveness of PjBL may depend on the type of skill

being developed, students' cognitive readiness, and the implementation context at each educational stage.

The strong effectiveness of PjBL at the junior high school level can be explained through Jean Piaget's theory of cognitive development. At this stage, students are typically in the concrete operational phase, meaning they can think logically about concrete objects but have not yet mastered abstract reasoning. Therefore, learning approaches involving direct activities such as projects, experiments, and contextual discussions are particularly suited to their developmental needs. PjBL allows students to connect mathematical concepts to real-life experiences, thereby strengthening learning through assimilation and accommodation (Erawati & Adnyana, 2024).

This finding is further supported by (Cerovac & Keane, 2024), who demonstrated that students at this stage struggle with abstract tasks unless supported by concrete representations, but perform better when given clear instructions and tangible models. Similarly, (Kaplan, 2018) emphasized that instructional approaches aligned with cognitive development stages—such as visual aids, hands-on activities, and collaborative work—significantly improve understanding and engagement.

From the perspective of sample size, the analysis found that PjBL had a greater effect in groups with 30 or fewer participants (g = 0,992) than in those with 31 or more participants (g = 0,671). Although this difference was not statistically significant (Qb = 2032; p = 0,154), it is practically meaningful. Smaller class sizes allow for more intensive interaction between teachers and students, as well as among students themselves. Project-based learning in small groups facilitates more effective project supervision, equitable participation in discussions, and greater opportunities for each student to express mathematical ideas. This aligns with the findings of (Sari et al., 2021), who concluded that learning models are generally more effective when applied in smaller group settings.

Although this meta-analysis presents a generally positive picture of PjBL's effectiveness, the high heterogeneity value (I^2 = 69,83%) indicates considerable variability among the included studies. This variation may stem from differences in intervention design, duration of implementation, quality of project execution, facilitator competencies, and differences in sociocultural contexts or student characteristics. Additionally, all studies analyzed were written in Bahasa Indonesia, meaning the generalizability of these results to international contexts must be approached with caution.

CONCLUSION

The results of this meta-analysis involving eight studies indicate that the Project-Based Learning (PjBL) model has a statistically significant and moderately (0,785) effective impact on students' Mathematical Communication Skills (MCS). On average, students who learned through PjBL exhibited MCS levels that were 78.38% higher than those who received conventional instruction. The greatest impact was observed at the junior high school level, consistent with Piaget's theory of cognitive development, which posits that students at this stage are in the concrete operational phase and therefore respond more positively to activity-based and collaborative learning approaches. Furthermore, PjBL was found to be more effective when applied

in smaller class sizes, as this allows for more intensive interaction and individualized support.

Overall, the findings support the implementation of PjBL in mathematics instruction, particularly at the junior high school level and in small-group settings. This model can serve as an effective alternative instructional strategy for teachers and policymakers seeking to enhance active and meaningful learning. However, given that most of the analyzed studies were sourced from Indonesian-language publications and that the results exhibited considerable variability, further research is recommended. Future studies should incorporate broader contexts, examine variables such as intervention duration, project types, and teacher competencies, and consider applying meta-regression approaches to gain deeper insights into the effectiveness of PjBL.

RECOMMENDATION

Future research is encouraged to broaden its scope by incorporating a larger number of studies from various educational levels and geographic contexts, including urban and rural areas, as well as students from diverse socioeconomic backgrounds. In addition, it is important to formulate more specific research questions—for example, by investigating the effectiveness of PjBL in enhancing other mathematical competencies such as problem-solving or critical thinking, and comparing its impact with traditional instructional models. Subsequent studies should also examine the influence of rarely explored moderator variables such as students' gender, teachers' teaching experience, and instructional duration. These variables can be explored using experimental or longitudinal study designs to gain a better understanding of the long-term effects and optimal conditions for implementing PjBL. Moreover, future research could focus on how PjBL can be adapted to various learning environments, including online, hybrid, and inclusive education settings for students with special needs. This approach will deepen our understanding of the flexibility, effectiveness, and relevance of PjBL across diverse educational contexts. Through these expanded efforts, future research is expected to provide more comprehensive guidance for teachers and policymakers in designing instructional strategies that are responsive to the diverse needs of learners.

Author Contributions

Abdur Rahman Hakim was responsible for formulating the research idea, designing the methodology, conducting the literature review, collecting the data, drafting the initial manuscript, and performing the data coding in collaboration with Firza Mufti Aulia. Hasanuddin provided conceptual guidance, academic supervision, and contributed to the critical review and substantive editing of the manuscript. Firza Mufti Aulia contributed to the data coding process, manuscript editing, and conducted the plagiarism check. Jung Won Lee contributed to the translation of the manuscript into English and provided linguistic editing.

Funding

This research did not receive any specific grant from public, commercial, or not-for-profit funding agencies.

Acknowledgment

The authors would like to express their sincere appreciation to all contributors who have supported the completion of this study. Special gratitude is extended to the co-authors for their valuable input, collaboration, and dedication throughout the process of writing, reviewing, and refining this article. The authors are particularly thankful to the international collaborators, whose involvement enriched the research with diverse academic perspectives and exemplified the spirit of global scholarly cooperation. Their willingness to engage across cultural and institutional boundaries has significantly enhanced the quality and depth of this study, and the authors look forward to continued collaboration in future academic endeavors.

Conflict of interests

The authors affirm that the research and publication process was conducted independently and free from any conflicts of interest.

REFERENCES

Ambarwati, R., Dwijanto, & Hendikawati, P. (2015). Keefektifan Model Project-Based Learning Berbasis GQM Terhadap Kemampuan Komunikasi Matematis dan Percaya Diri Siswa Kelas VII. *Unner Journal of Mathematics Education*, *4*(2), 180–186. https://doi.org/10.15294/ujme.v4i2.7601

Andriani, L., Suhirman, Ihsan, M. S., & Rahman, F. A. (2023). Pengaruh Model Pembelajaran Project Based Learning (PjBL) Terhadap Kemampuan Komunikasi dan Berpikir Kreatif Peserta Didik. *Jurnal Inovasi Pendidikan dan Sains*, *4*(2), 102–107. https://doi.org/10.51673/jips.v4i2.1590

Apriani, P., Fikriyah, F., & Susilawati. (2024). Penerapan Model PjBL Untuk Meningkatkan Kemampuan Komunikasi Pada Mata Pelajaran Matematika di SD Negeri 3 Patrol Lor. *J-CEKI: Jurnal Cendekia Ilmiah*, *3*(5), 3361–3368. https://doi.org/10.56799/jceki.v3i5.4737

Cerovac, M., & Keane, T. (2024). Early insights into Piaget's cognitive development model through the lens of the Technologies curriculum. *International Journal of Technology and Design Education*, *35*(1), 61–81. https://doi.org/10.1007/s10798-024-09906-5

Chalim, M. N., Mariani, S., & Wijayanti, K. (2019). Kemampuan Komunikasi Matematis Siswa SMK Ditinjau dari Self Efficacy pada Setting Pembelajaran Project Based Learning Terintegrasi STEM. *PRISMA: Prosiding Seminar Nasional Matematika*, *2*, 540–550. https://journal.unneas.ac.id/sju/prisma/article/view/29049

Erawati, N. K., & Adnyana, P. B. (2024). Implementation of Jean Peaget's Theory of Contructivism in Learning: A Literature Review. *Indonesian Journal of Educational Development (IJED)*, *5*(3), 394–401. https://doi.org/10.59672/ijed.v5i3.4148

Giovanti, L. L., Buchori, A., & Rahmawati, N. D. (2023). Efektivitas Problem Based Learning Berbantu Software Geogebra pada Materi Program Linear Terhadap Kemampuan Komunikasi Matematis Siswa SMA. *Jurnal Lebesgue: Jurnal Ilmiah Pendidikan Matematika*, *4*(3), 1765–1776. https://doi.org/10.46306/lb.v4i3

Haddaway, N. R., Page, M. J., Pritchard, C. C., & McGuinness, L. A. (2022). PRISMA2020: An R package and Shiny app for producing PRISMA 2020-

compliant flow diagrams, with interactivity for optimised digital transparency and Open Synthesis. *Campbell Systematic Reviews*, *18*(2), 1230. https://doi.org/10.1002/cl2.1230

Hansford, N., & Schechter, R. E. (2023). Challenges and Opportunities of Meta-Analysis in Education Research. *International Journal of Modern Education Studies*, *7*(1), 0–1. https://doi.org/10.51383/ijonmes.2023.313

Jais, E., Usa, S. La, & Intifadah, W. (2024). Pengaruh Model Project Based Learning (PjBL) Terhadap Kemampuan Komunikasi Matematis Siswa SMP Negeri 2 Baubau. *Jurnal Akademik Pendidikan Matematika*, *10*(1), 32–36. https://doi.org/10.55340/japm.v10i1.1522

Kaplan, D. E. (2018). Piagetian Theory in Online Teacher Education. *Creative Education*, *09*(06), 831–837. https://doi.org/10.4236/ce.2018.96061

Kufa, W. E., & Susilowaty, N. (2022). Meta Analisis Pengaruh Model Pembelajaran Discovery Learning Terhadap Kemampuan Matematis Siswa. *Jurnal Pedagogik*, *5*(2), 32–42. https://doi.org/10.35974/jpd.v5i2.2889

Lismayanti, N., Hutajulu, M., & Linda. (2024). Peningkatan Kemampuan Komunikasi Matematis Dengan Model Project Based Learning Berbantuan Geogebra: Solusi Inovatif Pendidikan Modern. *JPMI: Jurnal Pembelajaran Matematika Inovatif*, *7*(6), 30–40. https://doi.org/10.22460/jpmi.v7i6.25267

Lubis, M. J. K., Pangaribun, F., & Tambunan, H. (2024). Pengaruh Model Pembelajaran Project Based Learning Terhadap Kemampuan Komunikasi Matematis Dan Self Confidence Siswa. *Journal of Education*, *06*(02), 14842–14850. https://doi.org/10.31004/joe.v6i2.5356

Mahmudah, U. (2020). Meta Analisis Pengaruh Model Discovery Learning dan Problem Based Learning Terhadap Kemampuan Berpikir Kritis Matematis Peserta Didik Kelas V SD. *Thinking Skills and Creativity Journal*, *3*(2), 69–78. https://doi.org/10.23887/tscj.v3i2.29721

Mulyawati, S., Suwandono, & Rohman, M. S. (2018). Keefektifan Model Pembelajaran Berbasis Proyek (Project Based Learning) Terhadap Komunikasi Matematis dan Prestasi Belajar Matematika. *Integral (Jurnal Penelitian Pendidikan Matematika)*, *1*(1), 1–9. https://doi.org/10.24905/jppm.v1i1.17

Na'im, Z. N., & Mukhlis, M. (2024). Exploration of Students' Mathematical Communication Abilities. *Jurnal Riset Pendidikan Matematika*, *11*(1), 41–52. https://doi.org/10.21831/jrpm.v11i1.66639

Paloloang, M. F. B., Juandi, D., Tamur, M., Paloloang, B., & Adem, A. M. G. (2021). Meta-Analysis: Mengevaluasi Efektivitas Problem-Based Learning pada Kemampuan Pemahaman Matematis Siswa. *Journal of Honai Math*, *4*(1), 1–18. https://doi.org/10.24127/ajpm.v9i4.3049

Ramadhan, A. F., & Zaidal, N. (2024). Penerapan Data Mining dalam Pengelompokkan Penyebaran Data Mahasiswa Baru untuk Strategi Promosi Program Studi Teknik Informatika (Studi Kasus: IIB Darmajaya). *Scientica (Jurnal Ilmiah Sains dan Teknologi)*, *2*(2), 243–250. https://doi.org/10.572349/scientica.v2i2.1000

Ruqoyyah, S., Arga, H. S. P., Kelana, J. B., & Altaftazani, D. H. (2020). Pengaruh Model Project Based Learning Berbantuan Barang Bekas Terhadap Kemampuan Komunikasi Matematis Siswa Pendidikan Guru Sekolah Dasar. *Jurnal Ilmiah P2M*

STKIP Siliwangi, *7*(2), 126–133. https://doi.org/10.22460/p2m.v7i2p%25p.2008

Sari, Y. K., Juandi, D., Tamur, M., & Adem, A. M. G. (2021). Meta-Analysis: Mengevaluasi Efektivitas Problem Based Learning Pada Kemampuan Pemahaman Matematis Siswa. *Journal of Honai Math*, *4*(1), 1–18. https://doi.org/10.30862/jhm.v4i1.144

Sihombing, D. C., & Susilowaty, N. (2023). Meta Analisis Pengaruh Model Pembelajaran Berbasis Proyek Terhadap Kemampuan Matematis Siswa. *JP2M (Jurnal Pendidikan dan Pembelajaran Matematika)*, *9*(1), 136–145. https://doi.org/10.29100/jp2m.v9i1.4028

Sudianto, & Yaqin, S. Sy. (2024). Efektivitas Model Project Based Learning Berbantuan Canva Terhadap Kemampuan Komunikasi Matematis Siswa. *Jurnal Didactical Mathematics*, *6*(2), 323–332. https://doi.org/10.31949/dm.v6i2.11925

Sukmawati, A. (2020). Meta Analisis Model Problem Based Learning dalam Meningkatkan Kemampuan Berpikir Kritis pada Pembelajaran Matematika. *Thinking Skills and Creativity Journal*, *3*(2), 63–68. https://doi.org/10.23887/tscj.v3i2.30211

Susilowaty, N. (2023). Meta Analisis Pengaruh Model Pembelajaran Project Based Learning Terhadap Kemampuan Berpikir Kreatif Matematis Siswa. *Jurnal Pedagogik*, *6*(2), 41–50. https://doi.org/10.35974/jpd.v6i2.3139

Syarifah, L., Holisin, I., & Shoffa, S. (2021). Meta Analisis: Model Pembelajaran Project Based Learning. *Jurnal Penelitian Pembelajaran Matematika*, *14*(2), 256–272. https://doi.org/10.30870/jppm.v14i2.11905

Widyastuti, R., Jalinus, N., Ridwan, Abdullah, R., & Krismadinata. (2024). Meta Analisis Pengaruh Model PjBL Terhadap Kemampuan Berpikir Kreatif Peserta Didik. *Indonesian Journal of Computer Science*, *13*(3), 4863–4873. http://ijcs.stmikindonesia.ac.id/ijcs/index.php/ijcs/article/view/3135

Wilkinson, L. C., Bailey, A. L., & Maher, C. A. (2018). Students' Mathematical Reasoning, Communication, and Language Representations: A Video-Narrative Analysis. *ECNU Review of Education*, *1*(3), 1–22. https://doi.org/10.30926/ecnuroe2018010301