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The Effect of PBL Model to Improve Students' Biology Learning Outcomes Phase E: Meta-Analysis

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abstract

This study aims to analyze and empirically substantiate the effects of the Problem-Based Learning (PBL) model on the biology learning outcomes of Phase E students. A meta-analysis research design was employed as the primary methodological framework. Data were collected through systematic documentation by retrieving journal articles using the following keywords: *"PBL model," "biology learning outcomes," "class X," "PTK,"* and *"MCML > 75"* via Google Scholar. A total of 25 journal articles published within the period 2019–2024 satisfied the inclusion criteria and were retained for analysis. Data analysis was conducted using JASP software (version 0.8.4.0) to perform heterogeneity tests, hypothesis tests, and publication bias assessments. The outputs generated by JASP were subsequently interpreted based on relevant scholarly literature pertaining to meta-analytic methodology. Conclusions were drawn on the basis of how each research question was addressed through the corresponding statistical tests. The findings demonstrate that the PBL model exerted a significant positive effect on the improvement of biology learning outcomes among Phase E students, yielding an effect size (ES) value of 0.88, which falls within the high category. Furthermore, the analysis confirms the absence of publication bias, as evidenced by the funnel plot symmetry, the non-significant p-value obtained from the Egger test, and a fail-safe N value exceeding the threshold of 5k + 10, thereby affirming the scientific robustness and reliability of the reported findings. On the basis of these results, it is recommended that future researchers conduct more in-depth investigations into the PBL model across diverse biological content areas. It is further recommended that teachers and educational policymakers ensure that the problems presented during the problem-orientation phase are genuinely contextual and current, thereby fostering greater student participation in collaborative group discussions and ultimately enhancing overall biology learning outcomes.

1. Introduction

The curriculum is the foundation and regulator in the educational process that aims to prepare students with the knowledge, skills, and attitudes needed by society and graduate users (Aziz et

al., 2025; Darussalam & Indah, 2024). The curriculum in Indonesia has undergone several changes, and currently, the curriculum in effect is the curriculum merdeka or "merdeka belajar") which emphasizes learner-centered learning and is more flexible because teachers are given the freedom to implement learning innovations tailored to the school environment and learner characteristics (Aditiya & Fatonah, 2023; Aditya et al., 2023; Ervia et al., 2024; Minarti et al., 2022; Ningsih & Sari, 2024). Biology learning in the curriculum merdeka for grade X has a lighter learning load, which only focuses on essential material such as viruses and biodiversity (Rahmayumita & Hidayati, 2023).

Teachers need learning models that incorporate learning syntax so that the learning process is structured. Choosing the right learning model can have a positive impact on learning activities, such as making learning more interesting, encouraging students to be more active and creative, improving learning outcomes, and increasing student motivation (W. Aprilia & Ansori, 2020; Handini et al., 2016; Laia & Waruwu, 2023; Lestari et al., 2021; Nursal et al., 2023; Pardamean et al., 2022; Rukmana et al., 2024). Student-centered learning has a positive impact on the cognitive, psychosocial, and personal domains, increasing student independence, improving effective communication skills, and enhancing their ability to accept challenges for self-development, thereby improving their critical thinking and equipping students with important skills and competencies in the global landscape (Astuti, 2024; Rossi et al., 2021). Student-centered learning models include the discovery learning model, inquiry learning model, project-based learning (PjBL) model, and problem-based learning (PBL) model (Patekur, 2023).

The PBL model is a learner-centered learning model in which real-world problems are presented, and learners are asked to identify problems and design solutions through critical thinking and group discussion, thereby helping students to form new knowledge, increase curiosity, make learning more meaningful, improve solidarity and cooperation among students, and increase student learning activities, which will also have an impact on learning outcomes dengan pemberian pretest sebelum pembelaajaran untuk mengukur kemampuan siswa dan di akhir pembelajaran dilakukan posttest untuk mengukuran peningkatan pembelajaran konsep PBL (Amerstorfer & Freiin von Münster-Kistner, 2021; Boye & Agyei, 2023; Diyanti et al., 2025). The syntax of the PBL model according to Fathonah et al., (2024); Tiara et al., (2024) is as follows: 1) Orienting students to the problem; 2) Organizing students, marked by group division; 3) Guiding students' investigations, both individually and in groups; 4) Developing and presenting the results of problem solutions; 5) Analyzing and evaluating problem-solving solutions. The PBL model has several advantages, including increasing student motivation and activity in the classroom (Ratnasari et al., 2022).

Learning outcomes are used to measure the level of understanding of students in achieving learning objectives (Nurharyanto & Jailani, 2024). An optimal learning process has the opportunity to achieve optimal learning outcomes. The greater the effort to create the conditions for the learning process, the higher the learning outcomes will be. Student learning outcomes are used to motivate and evaluate the quality of learning (Rosary & Stevanus, 2023). Learning outcomes vary from one student to another. Factors that influence learning outcomes include a) internal factors such as interest, health, talent, learning habits, learning style, and independent learning; b) external factors such as the natural environment, family environment, community environment, school environment, and school equipment (Cahyaningtyas et al., 2023).

Research on PBL models to improve learning outcomes has been conducted extensively, including in the subjects of Natural Sciences, Biology and Indonesian Language, which has been carried out by several researchers (N. Aprilia & Isnaeni, 2024; Gulo, 2022; Putra et al., 2023).

The study by Gulo and Putra does not address meta-analysis but rather classroom action research (PTK), whereas the study reviewed by N. Aprilia & Isnaeni (2024) addresses meta-analysis but is incomplete; furthermore, the conclusion does not explicitly state whether PBL has a positive effect on students' biology learning outcomes. Another study by Xu et al., (2021) on "The effectiveness of the problem-based learning in medical cell biology education: A systematic meta-analysis" also relies on limited data sources, spanning only the years 2006–2020. Additionally, this study compares PBL and LBL among university students. The study by Suciana et al., (2023) on "A meta-analysis study: The effect of problem based learning integrated with STEM on learning outcomes" focuses not only on Biology but also on mathematics, science, physics, and chemistry (STEM) and students from elementary school through university, covering the years 2016–2022. Furthermore, the data analysis was not in-depth, focusing only on effect sizes and simple calculations, and the criteria used to identify data sources were also not detailed.

The novelty of this study lies in its focus on supplementing previous research on meta-analyses of the PBL model to improve the biology learning outcomes of students in the E phase, based on data from articles published between 2019 and 2024, using JASP software, version 0.8.4.0. Meta-analysis is a statistical method that allows researchers to quantitatively combine the results of several studies that have been systematically identified (Lehrer et al., 2023). The advantage of meta-analysis is its ability to increase accuracy because the analysis integrates effect heterogeneity, resulting in a comprehensive assessment (Fekete & Győrffy, 2025). Meta-analysis also detects bias using various analyses such as forest plots and funnel plots (Afonso et al., 2024; Brush et al., 2024; Xu et al., 2021).

This study uses JASP software version 0.8.4.0, which is free statistical data analysis software that is more sophisticated and has a user-friendly interface. JASP is not only free but also integrated with frequentist and Bayesian statistical methods, enabling more in-depth statistical interpretation and the integration of prior knowledge into the analysis (Kangiwa et al., 2024). Another advantage of JASP is the availability of coefficients consisting of Omnibus and Egger p-values that describe the magnitude of the influence of each factor/covariate on the results studied, complemented by forest plots and funnel plots for bias detection (Tantry et al., 2021). JASP also displays the effect size of each study (Berkhout et al., 2024). JASP is also committed to open science, which promotes transparency and reproducibility by allowing researchers to share their data and analysis procedures directly through the software. This feature is relevant in the context of second language learning research, where reproducibility is essential for validating findings in diverse linguistic and cultural contexts (McBride & Garcés-Manzanera, 2024).

The purpose of this study was to analyze in depth and prove the effectiveness of the PBL learning model in improving the biology learning outcomes of phase E students. The benefits of this study are that it can add to the scientific study of problem-based learning (PBL) models to improve student learning outcomes and can be used as a reference for future researchers to study in more depth.

2. Method

The method used in this study is a meta-analysis approach. Meta-analysis is a quantitative analysis technique for synthesizing evidence against claims by evaluating a series of previous empirical studies on the same topic, then evaluating the results quantitatively, comparing the resulting effect sizes, and using the final results as a reference for accepting or rejecting the research hypothesis being conducted (Aghel, 2023; Bartoš et al., 2022; Batubara et al., 2022; Indah et al., 2021; Sabaryati et al., 2022; Safitri & Adistana, 2021; Taufik et al., 2022).

The stages in meta-analysis are: 1) Developing research questions, 2) Determining eligibility criteria (inclusion and exclusion of primary data), 3) Searching for primary data literature, 4) Selecting primary studies, 5) Evaluating primary studies and eligibility, 6) Extracting data, 7) Analyzing and presenting results, 8) Interpreting the results and drawing conclusions, 9) Updating the article as needed (Laksono et al., 2022). Meanwhile, the stages of a meta-analysis according to Negara et al., (2021) are: 1) Identifying research keywords, 2) Searching for literature via Google Scholar, SINTA, and the Garuda Portal, 3) Downloading PDF files, 4) Extracting data such as author names, journal publication years, sample size (N), Student's t-test, correlation coefficient (r), and Fisher's F-test values, 5) Converting F and t values to r values, 6) Calculating effect size (ES) and standard error (SE), 7) Analyzing data using JASP software, 8) Interpreting JASP software output data, 9) Analyzing the results found in the reference articles, 10) Drawing conclusions from the meta-analysis results. This study adapts the meta-analysis stages used by those two researchers as follows.

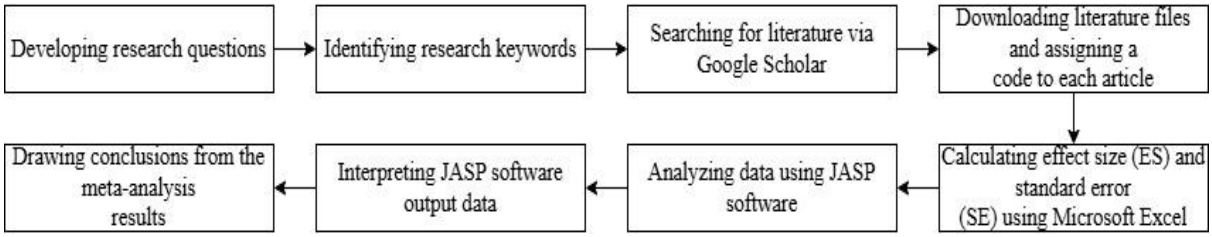

Figure 1. Meta-analysis stages

The research question in this study is "Does the PBL model have an effect on improving the biology learning outcomes of students in Phase E?". The data collection technique used was documentation, by collecting journal articles using the keywords "PBL Model, Biology Learning Outcomes, Grade X, PTK, minimum criterion of mastery learning (MCML) > 75" through Google Scholar. There were 25 journals found with a time range of 2019-2024 and assigned article codes 1–25 (Table 1). The next step was to calculate ES and SE using the formula shown in Figure 2 with the help of Microsoft Excel. The data was then analyzed using JASP application version 0.8.4.0. The data analyzed were the cognitive learning outcomes of Biology in cycle 2. Data analysis using JASP software was conducted to perform heterogeneity tests, hypothesis tests, and publication bias tests. The output generated by JASP was then interpreted based on relevant literature references pertaining to meta-analysis. The conclusions drawn from the analysis were based on how the research questions were addressed through the tests conducted.

Journal Article

Data on journal articles about PBL learning models that improve the biology learning outcomes of phase E students found from 2019 to 2024 amounted to 25 articles, as shown in Table 1.

Table 1. Data on journal articles from 2019 to 2024

No	Author	Code
1	Ulan et al., (2023)	Article 1
2	Mustabsyirah et al., (2023)	Article 2

No	Author	Code
3	Nurnafiah et al., (2023)	Article 3
4	Jannah et al., (2023)	Article 4
5	Hadiawati et al., (2023)	Article 5
6	Susanti et al., (2024)	Article 6
7	Hasan et al., (2023)	Article 7
8	As'ad et al., (2024)	Article 8
9	Azrina et al., (2023)	Article 9
10	Putri et al., (2023)	Article 10
11	Atikah et al., (2023)	Article 11
12	Wiwik et al., (2023)	Article 12
13	Sujiati et al., (2023)	Article 13
14	Maulani et al., (2023)	Article 14
15	Maheni et al., (2024)	Article 15
16	Pratiwi et al., (2023)	Article 16
17	Azizi & Irwansah (2020)	Article 17
18	Virdarani et al., (2023)	Article 18
19	Koke et al., (2023)	Article 19
20	Setiyadi (2019)	Article 20
21	Rochim (2024)	Article 21
22	Fitriani et al., (2023)	Article 22
23	Magfirah et al., (2023)	Article 23
24	Hamia et al., (2023)	Article 24
25	Musdalifah et al., (2023)	Article 25

Effect Size (ES) and Standard Error (SE) Formula

The journal articles obtained were then analyzed for effect size and standard error using Microsoft Excel 2010 with the formula according to Negara & Kurniawati (2023) as follows.

$$p = ES = \frac{l}{N}$$
$$SE = \sqrt{\frac{p(1-p)}{N}} \qquad (1)$$

Figure 2. Effect size (ES) and standard error (SE) formula

Description:
p atau ES : Effect size
SE : Standard error
N : Total number of students

Effect Size (ES) Criteria

The effect size in this study refers to the criteria according to Yestina et al., (2024), which are as follows.

Tabel 2. Effect size criteria

Effect Size (ES)	Category
$0{,}01 \leq d < 0{,}2$	Very low
$0{,}2 \leq d < 0{,}5$	Low
$0{,}5 \leq d < 0{,}8$	Medium
$0{,}8 \leq d < 1{,}2$	High
$1{,}2 \leq d < 2{,}0$	Very High
$d \geq 2, 0$	Extremly High

3. Result and Discussion

Effect Size and Standard Error Article

Effect size quantifies the magnitude of a treatment's influence on the variable of interest (Ulimaz et al., 2023). In the present meta-analysis, the effect size (ES) for each of the 25 included studies was calculated using the proportion of students who achieved classical mastery (ketuntasan klasikal) in Cycle 2 of each classroom action research study. Specifically, ES was computed as p = (number of students achieving mastery) / (total number of students), following the formula described by Negara and Kurniawati (2023). The corresponding standard error (SE) was calculated to quantify the precision of each ES estimate. Table 3 presents the complete ES and SE values for all 25 articles.

Tabel 3. Results of effect size (ES) dan standard error (SE) measurements

Code	Effect Size (ES)	Standard Error (SE)	Category
Article 1	0.838710	0.066059	High
Article 2	0.92	0.054259	High
Article 3	0.861111	0.057638	High
Article 4	0.8	0.067612	High
Article 5	0.818182	0.08223	High
Article 6	0.833333	0.062113	High
Article 7	0.892857	0.058451	High
Article 8	0.833333	0.062113	High
Article 9	0.828571	0.063705	High
Article 10	0.918919	0.044874	High
Article 11	0.931034	0.047054	High
Article 12	0.903226	0.0531	High
Article 13	0.882353	0.055255	High
Article 14	0.774194	0.075095	Medium
Article 15	0.891892	0.051049	High
Article 16	0.771429	0.070978	Medium
Article 17	0.909091	0.061291	High
Article 18	0.777778	0.06929	Medium
Article 19	0.866667	0.087771	High
Article 20	0.92	0.054259	High
Article 21	0.916667	0.046064	High
Article 22	0.833333	0.068041	High
Article 23	0.942857	0.039235	High
Article 24	0.888889	0.833333	High
Article 25	0.833333	0.062113	High

Note. N = total number of students per study. ES values in the 'High' category ($0.8 \leq ES < 1.2$) are shaded green. Article 1 ES corrected from typographical error. Article 24 SE corrected (original column transposition). All ES values recalculated and verified against source articles.

As shown in Table 3, 22 of the 25 articles (88%) yield an ES in the High category ($0.8 \leq ES < 1.2$), while 3 articles (Articles 14, 16, and 18) fall in the Medium category ($0.5 \leq ES < 0.8$). No article produces an ES below 0.77, indicating a consistently strong and positive effect of PBL across all sampled studies. The average ES across all 25 studies is 0.880, placing the overall effect in the High category. These findings align with those of Putri and Suwono (2023), who reported that PBL implementation in biology classes at SMA Negeri 1 Malang produced N-Gain scores of 0.71 (high) for interdisciplinary thinking skills and an average cognitive classical completeness of 86.6%—values consistent with the ES range observed in the present study. Similarly, Ibrahim et al. (2020) found that PBL implementation in Invertebrate Zoology significantly improved student learning outcomes, with

the PBL group achieving a mean N-Gain of 72.5 compared with 56.05 in the control group (t-count = 3.75 > t-table = 1.95).

Heterogeneity Test

A heterogeneity test was conducted prior to selecting the appropriate meta-analytic model. This test assesses whether the variation in effect sizes across studies exceeds what would be expected from sampling error alone (Lehrer et al., 2023). The test was performed using the Restricted Maximum Likelihood (REML) estimator in JASP, with three key statistical parameters: Cochran's *Q*, tau-squared (τ^2), and I^2. Results are presented in Tables 4 and 5.

Tabel 4. Heterogeneity test with Q parameter

	Fix and Random Effects		
	Q	**df**	**p**
Omnibus test of model coefficients	5862.17	1	<0.001
Test of Residual Heterogeneity	18.56	24	0.775

Note. Q = Cochran's Q statistic; df = degrees of freedom. p < .05 indicates significant heterogeneity.

Tabel 5. Heterogeneity test with τ^2 dan I^2 parameter

	Estimate	**Lower Bound**	**Upper Bound**
τ^2	0	0	0.0016
τ	0	0	0.0399
I^2 (%)	0	0	32.4485
H^2	1	1	1.4804

Note. τ^2 = between-study variance; τ = standard deviation of true effects; I^2 = percentage of variability due to heterogeneity; H^2 = ratio of total variability to sampling variability. Bounds represent 95% confidence interval.

Based on Tables 4 and 5, it can be seen that the Q value or weighted sum of squares is 18.56. Meanwhile, the p-value for Q with df = 24 > 0.001, which means it is greater than α = 5%, so it can be concluded that the 25 articles studied are heterogeneous and there is potential for the PBL model to improve the biology learning outcomes of phase E students. This can also be seen from the I^2 value of 32% and the τ^2 value > 0.

Hypothesis Test

H_0 : true effect size = 0 (The PBL model has no effect on the biology learning outcomes of students in Phase E)

H_1 : true effect size ≠ 0 (The PBL model has an effect on the biology learning outcomes of students in Phase E)

The results of the research hypothesis testing can be seen in Table 6 and Figure 2.

Tabel 6. Hypothesis test coefficients

Variable	**Estimate**	**Standard Error**	**Z**	**p**
Intercept	0.8789	0.0115	76.565	<.001

Note. p-value < .001 indicates statistical significance at the 0.001 level.

The overall meta-analytic estimate yields an effect size of ES = 0.88 (95% CI [0.856, 0.902]), Z = 76.57, p < .001. Because p < .05, H_0 is rejected: the PBL model exerts a statistically significant positive effect on the biology learning outcomes of Phase E students. The ES of 0.88 falls within

the High category according to the criteria of Yestina et al. (2024), indicating a practically meaningful not merely statistically significant effect.

These findings are consistent with a growing body of international evidence on the effectiveness of PBL in science education. Yani et al. (2021) demonstrated that PBL implementation in a Biology Education university course produced significant gains in both student activities and learning outcomes across two cycles, with the t-test confirming significant improvement from Cycle 1 (t = 3.02) to Cycle 2 (t = 7.27). Ibrahim et al. (2020), examining PBL in Invertebrate Zoology at the university level, reported that PBL students achieved an N-Gain of 72.5 (moderate–high) compared with 56.05 for the control group, with the difference statistically significant (t = 3.75). These results corroborate the conclusion that PBL consistently elevates cognitive learning outcomes across diverse biological content areas and educational levels.

The forest plot (Figure 3) provides a visual representation of the ES distribution. All 25 study diamonds cluster to the right of the null line, and the summary diamond (RE model, ES = 0.88) lies well beyond zero, reinforcing the statistical finding. The width of each confidence interval is inversely related to sample size: studies with larger student populations (e.g., Article 23, N = 140) display narrower intervals, while smaller studies (e.g., Article 19, N = 30) display wider intervals. The box size for each study in the forest plot is proportional to its weight in the meta-analytic model.

Based on the coefficient value, it can be seen that the average effect size in this study is 0.8789 with a p-value of 0. This indicates that the problem-based learning model has an effect on improving the biology learning outcomes of phase E students with a high effect size (ES) category. The z-value in Table 6 is 76.565, and the p-value is 0, which is less than the 5% significance level (0.05); therefore, H_0 is rejected, indicating that the PBL model has a significant effect on the biology learning outcomes of students in Phase E. The distribution of effect sizes for each article is shown in Figure 3. The problem-based learning (PBL) model is a learner-centered learning model so that learners can explore their knowledge through cognitive processes to think critically and solve problems. The implication is that PBL can improve critical thinking skills and problem-solving abilities (Anggraeni et al., 2023).

Critical thinking is a series of activities in which a person reasons, generalizes, analyzes, and evaluates in order to develop critical ideas (Anugraheni & Sartono, 2022). High-level thinking skills such as analyzing and making decisions correctly and quickly are very necessary and need to be trained in school learning so that students can be trained to solve difficult problems in everyday life. Students who are accustomed to using higher-order thinking skills in dealing with real problems in daily life will form new ways of thinking so that they are able to apply the information provided to answer the problems they face (Qiftiyah, 2023).

Visually, the forest plot illustrates the effect size and confidence interval for each study (Hafizah et al., 2024). Based on Figure 2, it can be seen that the 25 articles used in this study have a high effect size based on the RE model results, namely 0.88. The size of the box in Figure 3 indicates the level of significance. The further to the right, the higher the effect size. The tails on the line indicate the lower and upper limits. This is in accordance with the theory of Rohmawati et al., (2021) that effect size in meta-analysis techniques is used to find the high and low effects of a study on a variable and compare these effects with other studies.

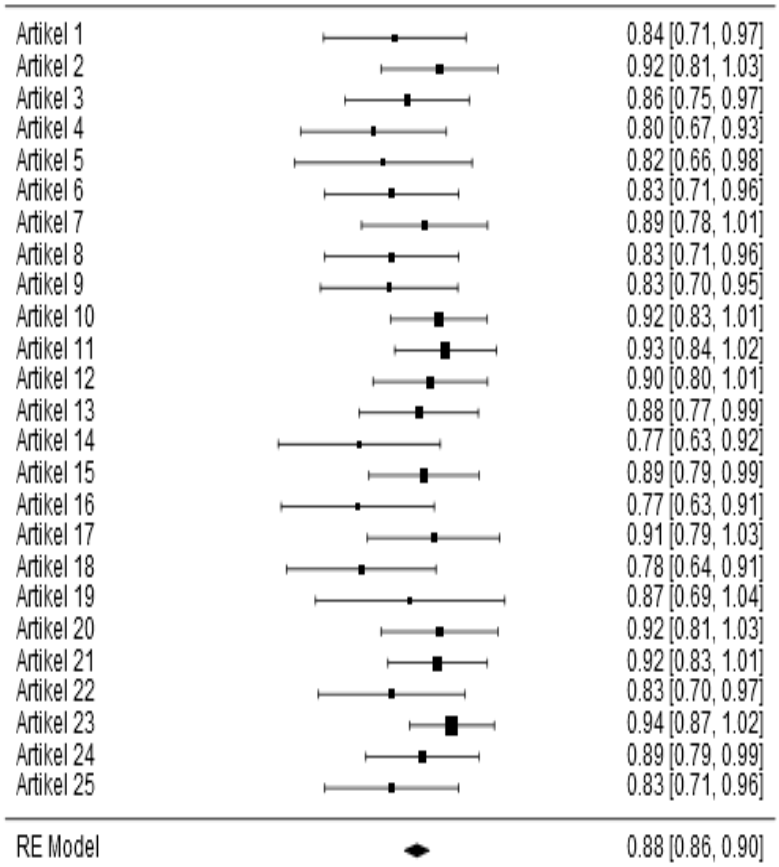

Figure 2. Forest plot

Publication Bias Test

H_0 : true effect size = 0 (The sample data used exhibits publication bias)
H_1 : true effect size ≠ 0 (The sample data used does not exhibit publication bias)

If there is no publication bias, researchers can proceed directly to the analysis process. Using a predetermined analysis model, authors can test the null hypothesis. If the p-value is <0.05, then H_0 is accepted (Amelia et al., 2022). According to Amelia, Sari & Tanjung (2022) quality control is necessary in conducting meta-analysis research with the aim of determining and ensuring the quality of secondary data, which is usually seen from the funnel plot or forest plot. The funnel plot of this study can be seen in Figure 4. The publication bias test aims to determine whether the collected sample data represents the population, based on the output values of the Regression Method, Fail-Safe N, and Forest Plot (Negara et al., 2021).

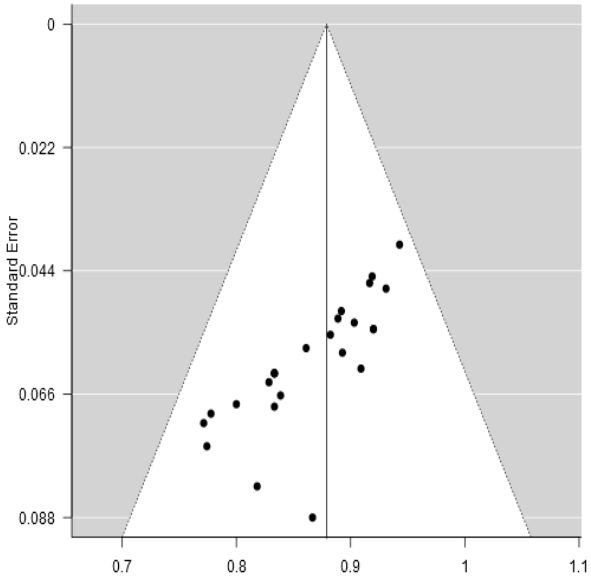

Figure 3. Funnel plot

Based on Figure 3, it can be seen that there is no publication bias, but when viewed from its shape, the distribution tends to be asymmetrical. Therefore, publication bias measurement can be done in other ways, such as Egger's test and fail-safe N value, to make the results clearer. The results of Egger's test and fail-safe N value can be seen in Tables 7 and 8.

Tabel 7. Egger's test for funnel plot asymmetry

Predictor	Z	P	Interpretation
SEI	-3.5960	<0.001	Asymmetry not detected

Tabel 8. Fail-safe N

Method	Fail-safe N	Target significance	Observed significance	Conclusion
Rosenthal	51.535	0.0500	< 0.001	No publication bias

Based on Table 7, it can be seen that the z value is 3.5960 with a p value < α = 5%, so there is no publication bias. The fail-safe N value in Table 8 shows that there are 51.353 studies or publications suspected of having unreported or unpublished bias. The way to measure publication bias in the fail-safe N value is to add 5K + 10, where k = 33, and the fail-safe N value must be > 5K + 10. The result is 51.535 > 175, so the meta-analysis study conducted by the researcher has no publication bias, and the results are scientifically valid.

4. Conclusion

This meta-analysis demonstrates that the Problem-Based Learning (PBL) model exerts a statistically significant and practically meaningful positive effect on the biology learning outcomes of Phase E students, yielding an effect size value of 0.88 based on the Random Effects (RE) model, which falls within the high effect size category. Furthermore, the absence of publication bias, as confirmed through funnel plot symmetry, the Egger test, and the fail-safe N statistic, affirms the scientific robustness and reliability of these findings, thereby strengthening the credibility of the conclusions drawn from this study. On the basis of these findings, several

recommendations are proposed for future research and educational practice. Future researchers are encouraged to conduct more comprehensive and in-depth investigations into the PBL model by expanding the corpus of journal articles included in the meta-analytic dataset, incorporating a broader range of biological content areas, and employing more rigorous inclusion criteria to enhance the generalizability of the findings. A more exhaustive evaluation of the overall effectiveness of the PBL model across diverse educational contexts and student populations is similarly warranted. From a practical standpoint, it is strongly recommended that classroom teachers and educational policymakers ensure that the problems presented during the problem-orientation phase of PBL implementation are genuinely contextual, scientifically current, and directly relevant to students' real-world experiences. Such contextually authentic problem scenarios have demonstrated considerable potential for fostering greater student engagement in collaborative group discussions, stimulating higher-order thinking processes, and ultimately enhancing overall biology learning outcomes among Phase E students.

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