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Effectiveness of problem-based learning on science problem-solving skills: A meta-analysis

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ABSTRACT
The research aimed to test the effectiveness of problem-based learning in improving science problem-solving skills through a meta-analysis of summary effect-size data. The sample in this study included 25 articles that discussed learners' science problem-solving skills through problem-based learning (PBL) application at the primary, lower secondary, upper secondary, and university levels. The fields of study include integrated science, physics, chemistry, biology, and ICT. This study used the group contrast meta-analysis method. The research consisted of an effect size analysis of the experimental and control classes of articles. The analysis used JASP software to test heterogeneity, summary effect size, and publication bias. The results showed that the summary effect size using the random effect model was 1.33, with a lower limit interval of 0.58 and an upper limit interval of 2.08. This value is in the high category with Cohen's U_3 (%) 90,82%. Therefore, it can be concluded that problem-based learning is effective for improving science problem-solving skills. The overall moderator test shows that educational level ($p > 0.05$) and science discipline ($p > 0.05$) do not have significant differences. Thus, the level of education and scientific disciplines in the application of PBL does not affect problem-solving skills. Therefore, PBL can be applied at various levels of education and scientific disciplines. The novelty of this study is that there are significant differences between individual studies ($p < 0.001$), which indicates the possible influence of other factors or variables that occur during the implementation of PBL in the classroom.

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Introduction

The benefit of problem-based learning is that it can enhance learners' problem-solving abilities by requiring active engagement and critical thinking at each stage of learning (Pitriah et al., 2018). One of the 21st-century skills learners must acquire is problem-solving (Jayadi et al., 2020), as goal-achievement and academic achievement depend on effective problem-solving techniques (Setiawan & Supiandi, 2019). The problem in schools is that pupils still have very low problem-solving skills due to the impact of teacher-centred learning activities, which make them passive during the learning process (Sahyar et al., 2017). Therefore, a learner-centred learning process is needed, one aspect of which is problem-based learning. In problem-based learning, there is an activity stage that involves independent learning by solving problems from various sources (Sahyar et al., 2017). Learners thereby acquire the capacity for critical thought and to deal with challenging situations (Supiandi & Ege, 2019). Research by Argaw et al. (2017) suggested that demonstrated activeness and problem-solving abilities were enhanced by problem-based learning.

Problem-solving skills training can be carried out through the application of learning models that create an effective learning environment to encourage learner activity and achieve learning goals (Nurhidayati et al., 2018). Research conducted by Pitaloka & Suyanto (2019) suggested that problem-based learning is effective in improving problem-solving skills in biology. Problem-solving is enhanced when problem-based learning is applied in science lectures. (Argaw et al., 2017). Research by Simanjuntak et al. (2021) states that problem-based learning helps learners understand a problem and find solutions. Bilgin et al. (2009) reported that students who used the problem-based learning (PBL) method demonstrated better problem-solving skills than those who did not. Fauziah et al. (2014) emphasized that students' problem-solving ability in PBL was superior to that in other learning models.

Problem-based learning (PBL) models can be applied in various fields of study. PBL has been proven to improve problem-solving skills in biology, ecology, physics, and other fields (J. Damayanti et al., 2021). This method is suitable for all levels of education, including high school students, as shown by Mundilarto & Ismoyo (2017), who reported an increase in students' problem-solving abilities. Various studies also show that applying PBL improves critical thinking, scientific literacy, and problem-solving skills at various levels of education (Chileya & Shumba, 2020; Jandrić et al., 2016). In addition to its positive aspects, PBL also has weaknesses. Abidin (2014) points out several weaknesses of PBL, such as first-year students who are reluctant to seek solutions because they consider the problems too difficult; students who are accustomed to obtaining information directly from primary sources find it difficult when they have to study independently; and they need to understand the reasons why they have to seek solutions. Therefore, applying PBL to improve science problem-solving skills also poses challenges for teachers, especially during implementation.

The widespread adoption of problem-based learning in education requires a summary of studies on its effectiveness (Cebrero, 2025). It is about how well learners' problem-solving skills have improved through problem-based learning at various levels of education and disciplines. Hopefully, this would improve the organisation of the existing research findings and make them more accessible to readers and prospective researchers. A meta-analysis of PBL's impact on students' science problem-solving at various educational levels is required. Various studies conducted by earlier researchers exclusively explore PBL concerning problem-solving at specific educational levels, for instance, only at the junior high school level or only at the senior high school level. In addition, earlier research covered only one branch of science, such as physics, chemistry, or biology. This meta-analytic study can serve as a foundation for future research and as a guide for educational institutions as they make decisions about existing curricula across all scientific disciplines, from primary schools to post-secondary universities. In light of this, researchers conducted a meta-analysis to examine the impact of PBL on learners' problem-solving abilities and interpret the findings of diverse PBL studies. The purpose of this study is to test the effectiveness of problem-based learning on science problem-solving skills through a meta-analysis of summary effect-size data. Specifically, the research aims to answer the following questions:

1. How effective is PBL in improving learners’ problem-solving skills?
2. Is there a significant difference between the effect size of educational level on problem- solving skills using PBL in science?
3. Is there a significant difference between the effect size of scientific disciplines on problem-solving skills using PBL in science?

This research can expand on and complement several previous studies that discuss the effect of problem-based learning on students' problem-solving skills. This study examines the extent of the problem-based learning model's effect across various fields of science and at different educational levels, from elementary school through junior high school, senior high school, and university. This study summarizes several fields of science, including natural sciences, physics, chemistry, biology, and ICT. This research is different from previous meta-analysis studies. For example, research by Funa & Prudente (2021) explains the effectiveness of PBL on student achievement at the secondary education level. The lack of meta-analyses examining the influence of PBL on problem-solving across all levels of education and scientific disciplines has prompted this meta-analysis. The results of this study provide educators with guidance on improving learners' problem-solving skills by applying problem-based learning in science instruction across various educational levels.

Methods

Research Design

This research is a meta-analysis that synthesizes the findings of similar studies. The meta-analysis uses results from previous research to draw systematic, accurate quantitative conclusions (Retnawati et al., 2018). This study applies the group contrast method, whereas some earlier meta-analyses used the correlation approach based on correlation coefficients. The data analyzed include the number of students, the mean scores, and the standard deviations from two different groups. This study includes various articles that examine how problem-based learning (PBL) might help learners improve their problem-solving abilities in the sciences. To examine whether there is a difference in effectiveness between problem-based learning (PBL) and other (non-PBL) models in science problem-solving skills, this meta-analysis comprises two groups: an experimental and a control group. The meta-analysis procedure of this study refers to Borenstein et al. (2009) and Retnawati et al. (2018), which are: (1) determine the inclusion criteria; (2) collect data and code variables; and (3) conduct data analysis.

Inclusion Criteria

A quantitative research design must be applied in all articles cited in this study. The criteria for the articles used in this study are (1) articles that examine how problem-based learning (PBL) affects or has an impact on solving scientific problems; (2) articles present data in the form of the number of samples, average values, standard deviations (group contrast); (3) articles published in reputable international journals and accredited national journals. Articles that do not meet the criteria will not be included in the meta-analysis procedure.

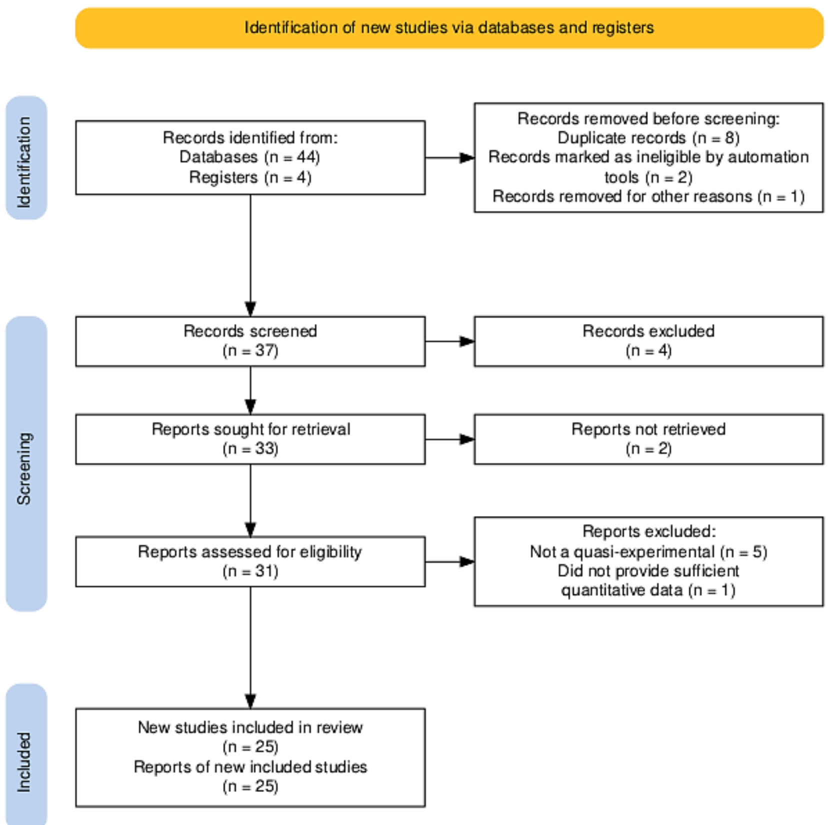
Data Collection

The primary data used are research articles on the relationship between learners' problem-solving ability and problem-based learning. The article collection technique involves searching for articles from various online journal portals such as the Education Resources Information Center (ERIC), Journal Storage

(JSTOR), and SCOPUS. Researchers collected 48 articles relevant to the research focus. Of the 48 articles, only 25 were found, and these included data on the number of samples, the mean, and the standard deviation. 25 papers met these requirements and discussed the value of problem-based learning across different educational levels, specifically in primary and junior high schools, as well as in senior high schools and universities. The fields of scientific study discussed include integrated science, physics, chemistry, biology, and ICT. Figure 1 depicts the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) diagram-based flowchart of the article search process.

Figure 1

PRISMA search strategy diagram



Statistical Analysis

The JASP (Jeffrey's Amazing Statistics Program) software was utilised for this investigation. JASP has several advantages, which are: (1) it is free; (2) it is multisystem; (3) its display is simple and easy to use; (4) it has a complete analysis menu; (5) there are various techniques in the meta-analysis, such fix and random effects analysis, fixed and mixed effect meta-regression, forest and funnel plots, trim and fill, and fail-safe N analysis. The steps of this study's meta-analysis are (1) the calculation of the effect size (g) and standard error (SEg), sourced from data on the number of samples, averages, standard deviations, and standard correlations using Microsoft Excel software; (2) heterogeneity testing; (3) summary effect size calculation; and (4) publication bias analysis. Effect size parameters of 0.1 (low), 0.1-0.4 (moderate), and 0.4

(high) values (Cohen, 1988).

The random-effects model was employed under the assumption that true effect sizes vary across studies, with heterogeneity indicated by $I^2 > 25\%$ (Retnawati et al., 2018). The parameters tau-squared (τ^2) and I^2 are used in a heterogeneous test. Heterogeneous test results indicate that the analysis is suitable for the random-effect model (Rosdiana, 2021). A statistical study must be tested for publication bias (Juandi & Tamur, 2020; Retnawati et al., 2018). The Fail-Safe N approach, the Trim and Fill approach, and the Begg-Mazumdar test are all used in the bias publication test (Rosenthal, 1979). If fail-safe N > (5K + 10), where K is the number of samples, then the meta-analysis is not biased. (Mullen et al., 2001). If the Trim and Fill method detects changes in the forest plot and displays white circles in the funnel plot, this indicates publication bias (Retnawati et al., 2018).

Findings

Primary Data Review

There are two studies at the primary school level (f = 2), four at the junior high school level (f = 4), eleven at the high school level (f = 11), and eight at the tertiary level (f = 8), as per Table 1.

Table 1

Data on the distribution

Educational Level	Frequency(f)	Percentage
Primary School	2	8%
Junior High School	4	16%
Senior High School	11	44%
College	8	32%
Total	25	100%

As shown in Table 2, there are nine natural science studies (f = 9), eight physics studies (f = 8), two biology studies (f = 2), four chemistry studies (f = 4), and two ICT studies. (f = 2).

Table 2

Data on the distribution of science study fields

Field of Study	Frequency (f)	Percentage
Natural Science	9	36%
Physics	8	32%
Biology	2	8%
Chemistry	4	16%
ICT	2	8%
Total	25	100%

Data Coding

The researcher coded the data from each study using the 25 articles that met the meta-analysis requirements. Based on the number of samples, mean, and standard deviation for each experimental and control group, a total of 25 articles were coded.

Table 3

Coding of study data based on contrast group data

No	Studies	Experiment Group			Control Group		
		n	Mean	SD	N	Mean	SD
1	(Pitaloka & Suyanto, 2019)	30	80	13.1	28	54.91	11.84
2	(Simanjuntak et al., 2021)	68	79.34	8.47	64	68.25	10.5
3	(Yuberti et al., 2019)	34	81.56	9.93	36	71.08	10.02
4	(Argaw et al., 2017)	40	50.25	16.091	41	38.54	15.742
5	(Sahin, 2010)	55	30.05	3.66	69	29.03	3.7
6	(Simone, 2008)	38	2.61	0.495	38	2.18	0.457
7	(Bilgin et al., 2009)	40	15.8	2.31	38	15.16	2.14
8	(Aidoo et al., 2016)	51	31.76	4.394	51	19.98	7.279
9	(Valdez & Bungihan, 2019)	46	0.73	0.41	50	0.4	0.21
10	(Surur et al., 2020)	60	6.47	2.062	60	5.38	2.164
11	(Anazifa & Djukri, 2017)	30	59.77	16.05	30	59.45	17.07
12	(Mundilarto & Ismoyo, 2017)	32	73.01	9.75	32	53.75	10.99
13	(J. Damayanti et al., 2021)	30	69	14.35	30	60.5	12.41
14	(Fauziah et al., 2014)	91	61.32	11.21	89	60.4	11.39
15	(Nantha et al., 2022)	29	63.91	0.31	31	60.42	0.28
16	(Sari et al., 2021)	32	68.44	9.019	30	59.83	7.008
17	(Santuthi et al., 2020)	28	84.44	6.839	30	75.19	12.945
18	(Simarmata & Sirait, 2019)	33	66.9	5.77	32	43.3	4.6
19	(Sahyar & Fitri, 2017)	34	84.47	6.34	34	77.18	5.62
20	(Chileya & Shumba, 2020)	41	62	10.583	51	34.16	9.72
21	(Çeliker & Dere, 2022)	21	59.8	7.21	22	57.09	6.92
22	(Akınoğlu & Tandoğan, 2007)	25	12.76	4.265	25	10.12	3.9404
23	(Jandrić et al., 2016)	58	36.41	6.74	54	28.33	6.87
24	(Tsai & Tang, 2017)	26	114.62	9.06	15	107.38	4.71
25	(M.Damayanti &Jirana, 2022)	29	83.43	10.13	30	79.67	10.12

Calculation of Effect Size

Using group contrast calculations, the researcher can estimate the effect size and the standard error based on the sample size, the average, and the given standard deviation. Table 4 presents effect sizes and standard errors for each study.

Table 4

Effect size and standard error based on contrast group data

Studies	Swithin	D	SEd	Df	J	g	SEg
(Pitaloka & Suyanto, 2019)	12.508	2.006	0.322	56	0.987	1.979	0.320
(Simanjuntak et al., 2021)	9.508	1.166	0.188	130	0.994	1.160	0.188
(Yuberti et al., 2019)	9.976	1.050	0.255	68	0.989	1.039	0.254
(Argaw et al., 2017)	15.915	0.736	0.230	79	0.990	0.729	0.229
(Sahin, 2010)	3.682	0.277	0.182	122	0.994	0.275	0.181
(Simone, 2008)	0.476	0.903	0.241	74	0.990	0.893	0.240
(Bilgin et al., 2009)	2.229	0.287	0.228	76	0.990	0.284	0.227
(Aidoo et al., 2016)	6.012	1.959	0.241	100	0.992	1.945	0.240
(Valdez & Bungihan, 2019)	0.322	1.026	0.217	94	0.992	1.018	0.216
(Surur et al., 2020)	2.114	0.516	0.186	118	0.994	0.512	0.185
(Anazifa & Djukri, 2017)	16.568	0.019	0.258	58	0.987	0.019	0.257
(Mundilarto & Ismoyo, 2017)	10.389	1.854	0.299	62	0.988	1.831	0.297
(J. Damayanti et al., 2021)	13.415	0.634	0.265	58	0.987	0.625	0.263
(Fauziah et al., 2014)	11.299	0.081	0.149	178	0.996	0.081	0.149
(Nantha et al., 2022)	0.295	11.836	1.111	58	0.987	11.682	1.104
(Sari et al., 2021)	8.110	1.062	0.271	60	0.987	1.048	0.270
(Santuthi et al., 2020)	10.456	0.885	0.275	56	0.987	0.873	0.273
(Simarmata & Sirait, 2019)	5.227	4.515	0.467	63	0.988	4.461	0.464
(Sahyar & Fitri, 2017)	5.991	1.217	0.264	66	0.989	1.203	0.263
(Chileya & Shumba, 2020)	10.113	2.753	0.292	90	0.992	2.730	0.291
(Çeliker & Dere, 2022)	7.063	0.384	0.308	41	0.982	0.377	0.305
(Akınoğlu & Tandoğan, 2007)	4.106	0.643	0.290	48	0.984	0.633	0.288
(Jandrić et al., 2016)	6.803	1.188	0.205	110	0.993	1.180	0.204
(Tsai & Tang, 2017)	7.783	0.930	0.340	39	0.981	0.912	0.337
(M. Damayanti & Jirana, 2022)	10.125	0.371	0.263	57	0.987	0.366	0.261

Table 4 presents the calculated effect sizes for each included study. The Cohen's d (D) values were obtained from the mean and standard deviation of the respective groups and then adjusted using the correction factor J to produce Hedges' g (g), which provides a less biased estimate for small sample sizes. The columns SEd and SEg indicate the standard errors of Cohen's d and Hedges' g, while **df** refers to the degrees of freedom derived from the sample size of each study. These results serve as the basis for subsequent analyses, such as constructing the forest plot and estimating the overall effect size in the meta-analysis.

Heterogeneity Test

Based on effect sizes and standard errors from all studies, an analysis was conducted using JASP. Based on the data in Table 5, τ^2 is 3.545 and τ is 1.883. The effect sizes of the studies used in the meta-analysis are heterogeneous if $\tau^2 > 0$ or $\tau > 0$. In addition, the data shows that I2 reaches 98.341%. If the I^2 value is >25% and is approaching 100%, the heterogeneity of the effect sizes across studies will be greater (Retnawati et al., 2018). Thus, it can be concluded that there is high heterogeneity in the effect size of each study, so that the selection of this random effect model is suitable for use and meets the criteria

Table 5

Heterogeneity Test Results

Residual Heterogeneity Estimates			
		95% Confidence Interval	
	Estimate	Lower	Upper
τ^2	3.545	2.409	9.647
τ	1.883	1.552	3.106
I^2 (%)	98.341	97.578	99.384

Summary Effect Size Analysis (Forest Plot)

To test the effectiveness level of applying problem-based learning. A summary effect size analysis was conducted using forest plots of all studies. According to the statistics in Table 6, there is a strong positive relationship between PBL and problem-solving abilities. The summary effect size was 1.329, with a 95% confidence interval ranging from 0.580 to 2.078. It found that PBL has a strong impact on learners' capacity to solve scientific problems.

Table 6

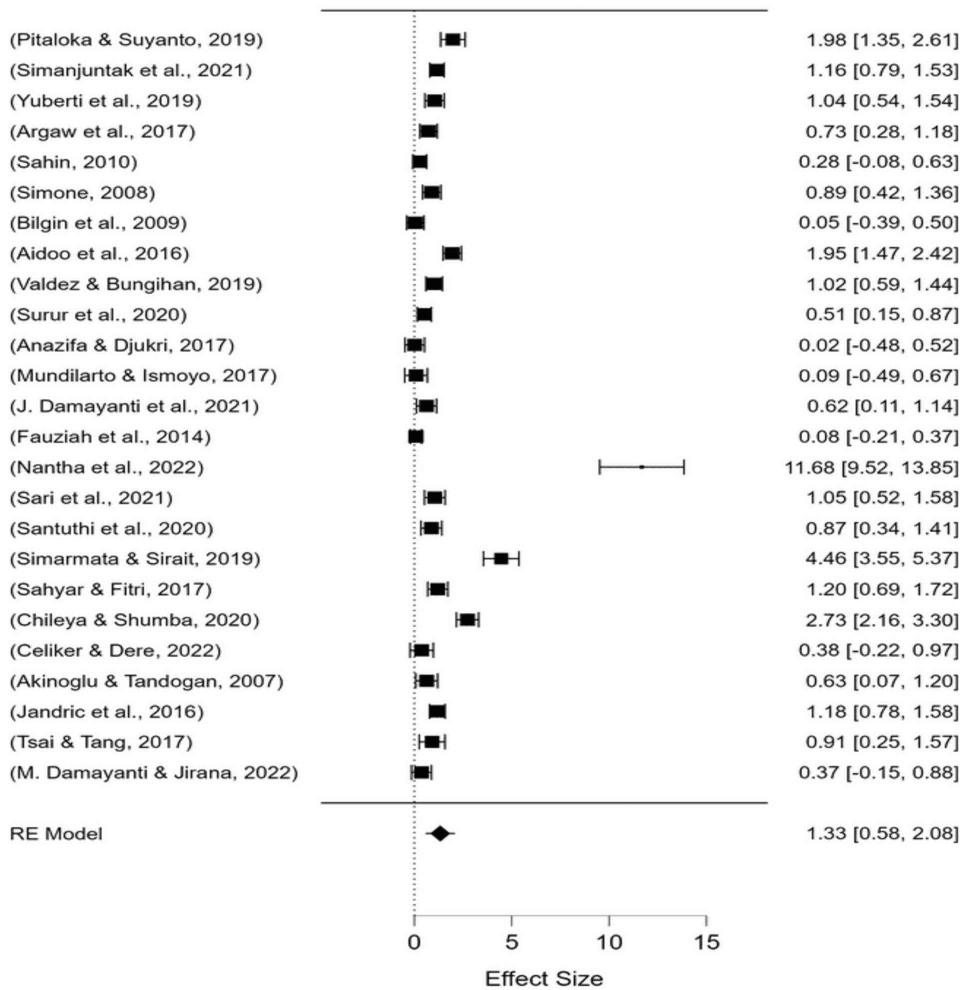
Summary of effect size results

					95% Confidence Interval	
	Estimate	Standard Error	Z	p	Lower	Upper
Intercept	1.329	0.382	3.477	< .001	0.580	2.078

The distribution of effect sizes across studies was presented in a forest plot. Figure 2's statistics demonstrate a summary effect of 1.33. There is a 133% difference between the experimental group (students who study using the PBL model) and the control group in terms of their ability to solve science-related problems, with Cohen's U_3 (%) at 90,82%. The summary effect size is in the range of 0.58 to 2.08, indicating that it is > 0. This demonstrates that using the PBL model to improve science problem-solving is highly effective. Students who study using the PBL model have much better problem-solving skills than those who learn using non-PBL models. These findings support previous research suggesting that PBL effectively improves learners' problem-solving capabilities in science courses (Argaw et al., 2017; Pitaloka & Suyanto, 2019; Santuthi et al., 2020; Sari et al., 2021; Simarmata & Sirait, 2019; Valdez & Bungihan, 2019).

Figure 2

A forest plot illustrating the effect size distribution for each study



The forest plot illustrates the effect sizes and 95% confidence intervals of the included studies. Each black square represents the effect size of an individual study, with the horizontal line indicating the confidence interval. The size of the square reflects the study's weight in the meta-analysis. The overall effect size, estimated using a random-effects model, is represented by the diamond (◆) at the bottom of the plot. The pooled effect size was 1.33 [0.58, 2.08]**,** indicating **a** moderate-to-large effect**,** with a confidence interval that does not cross zero, suggesting statistical significance. Some studies reported very large effect sizes, such as Nantha et al. (2022) with 11.68 [9.52, 13.85] and Simarmata & Sirait (2019) with 4.46 [3.55, 5.37]**,** while others showed negligible effects, for example, Anazifa & Djukri (2017) with 0.02 [-0.48, 0.52]**.** Despite this variability, the pooled result suggests that the intervention had a positive and meaningful impact overall.

Publication Bias Analysis

The fail-safe N method and the trim-and-fill method are used to test for publication bias in the following stage. Publication bias in meta-analysis can be examined using several statistical approaches. The Fail-safe N method (Rosenthal, 1979) estimates the number of unpublished or non-significant studies required to reduce the overall effect size to a non-significant level. A large fail-safe N indicates that the results are robust against publication bias. Meanwhile, the Trim and Fill method (Duval & Tweedie, 2000) detects asymmetry in the funnel plot. It corrects it by trimming asymmetric studies and imputing the missing ones, providing an adjusted estimate of the effect size. With a target significance of 0.05 and an observed significance of 0.001, Table 7 reveals that the fail-safe N value was 3563.000. The value (5K + 10) is 135. No publication bias exists in this meta-analysis study, as indicated by the value of fail-safe N > (5K + 10).

Table 7

Publication bias test through the fail-safe N method

File Drawer Analysis			
	Fail-safe N	Target Significance	Observed Significance
Rosenthal	3563.000	0.050	< .001

The trim-and-fill method test uses a funnel plot generated from JASP output. The funnel plot image shows that there are no white circle dots, and all dots are completely black. Based on these data, no unpublished research was found. Therefore, there is no evidence of publication bias in the researcher's meta-analysis. The funnel plot's appearance after the trim-and-fill method analysis supports this. As noted in Figure 3, there are no white open circles in the funnel plot, indicating that there is no publication bias. Thus, the conclusion from the random-effect model regarding the effectiveness of PBL on students' science problem-solving skills is valid and free of publication bias. This is supported by the forest plot in Figure 4, which shows the results before and after applying the Trim and Fill technique. Apart from that, to strengthen this, the Begg-Mazumdar Test was performed, as presented in Table 8.

Table 8

Publication bias test through the Begg-Mazumdar

Rank correlation test for Funnel plot asymmetry		
	Kendall's τ	p
Rank test	0.268	0.062

The Begg and Mazumdar's rank correlation test yielded a Kendall's τ of 0.268 with a p-value of 0.062. The result indicates a positive but weak correlation between sample size and effect size, which was not statistically significant ($p > 0.05$). Therefore, there is insufficient evidence to suggest funnel plot asymmetry or publication bias in this meta-analysis.

Figure 3

Funnel plot publication bias test using the trim and fill method.

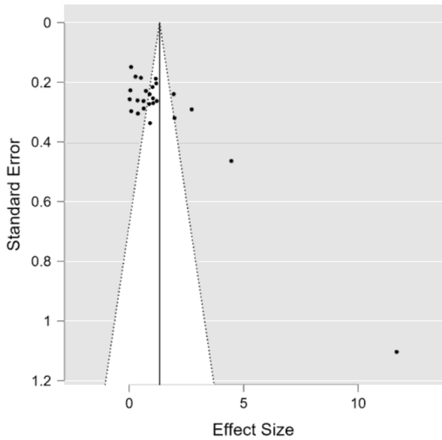
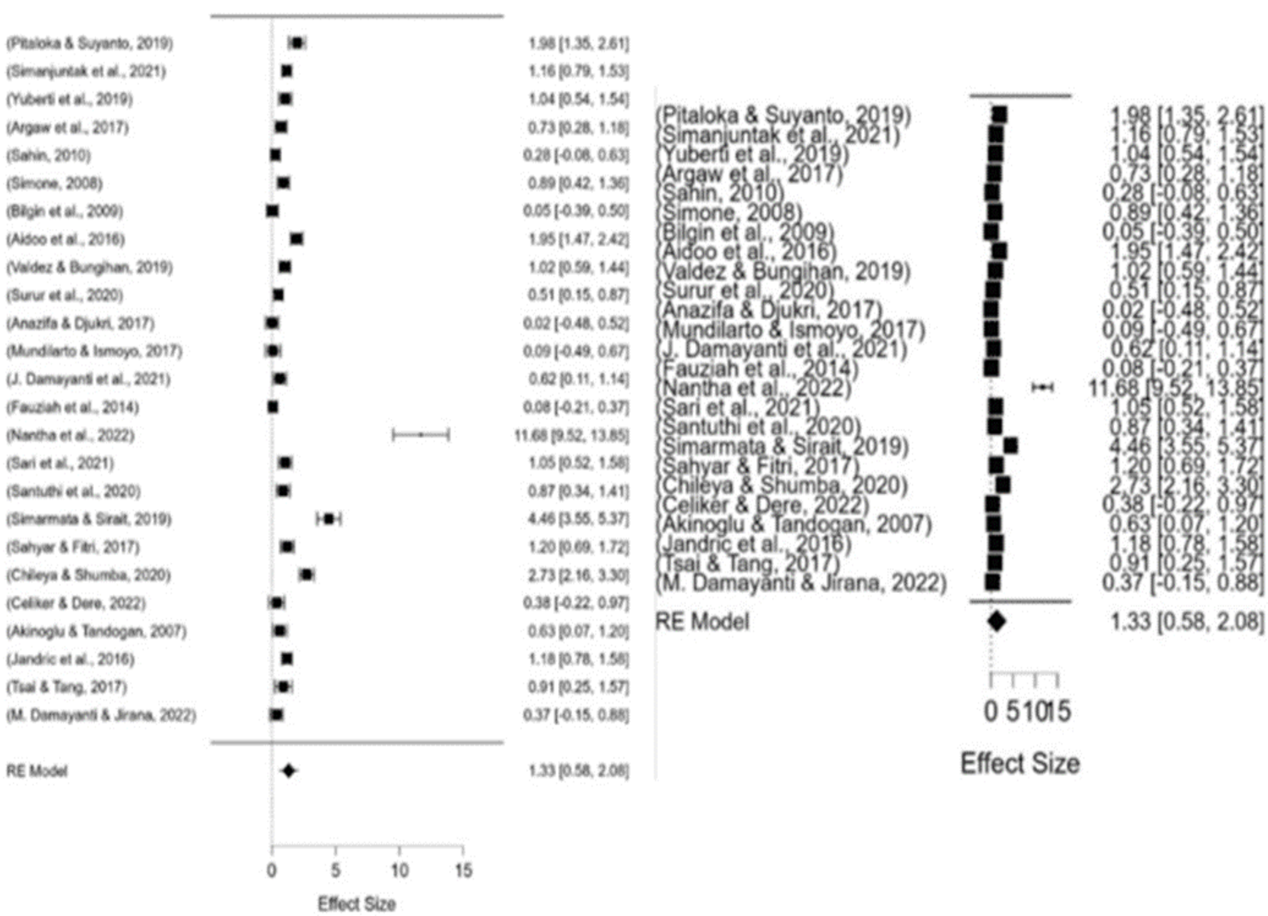


Figure 4

(a) Forest plot before publication testing; (b) Forest plot after publication testing, using the trim and fill method



(a) (b)

Based on the data in Figure 2, the funnel plot is asymmetric. However, the Begg-Mazumdar test yielded a p-value of 0.062 ($p > 0.05$). This shows that there is no publication bias in this meta-analysis. The rank correlation test is a statistical development proposed by Begg and Mazumdar. The funnel plot asymmetry does not necessarily indicate publication bias in the meta-analysis, especially when the sample sizes are small (Harbord *et al.*, 2009). It is not possible to determine if a funnel plot is symmetrical or asymmetrical using funnel plot analysis (Retnawati *et al.*, 2018). To determine significant differences in effect sizes between groups based on educational level and scientific discipline, a moderator analysis was conducted and is presented in Table 9.

Table 9

Moderator Analysis of educational level and scientific discipline

Moderator Random Effects Model	K	ES	SE	95% CI		Z	P	Heterogenity		
				Lower	Upper			Q	df	p
Level of Education	25	0.87	0.23	0.39	1.36	3.51	<.001	4.65	3	0.20
PS	2	0.62	0.55	-0.46	1.67	1.13	0.26			
JHS	4	0.63	0.13	0.34	0.89	4.73	<.001			
SHS	11	1.35	0.34	0.68	2.02	3.96	<.001			
Tertiary	8	1.82	1.32	-0.76	4.40	1.38	0.17			
Scientific Discipline	25	0.77	0.16	0.47	1.07	4.97	<.001	3.03	4	0.55
Natural Science	9	0.66	0.13	0.41	0.91	5.17	<.001			
Physics	8	1.09	0.48	0.16	2.02	2.29	0.02			
Biology	2	1.00	0.98	-0.93	2.91	1.01	0.31			
Chemistry	4	1.13	0.45	0.25	2.01	2.5	0.01			
ICT	2	6.56	5.07	-3.37	16.5	1.23	0.20			

The moderator analysis aims to determine significant differences in effect size by educational level and scientific discipline in students' problem-solving skills when using problem-based learning. The effect size for the overall level of education was large, at 0.87. According to the results of heterogeneity based on educational level, $p > 0.05$, there is no significant difference. PBL applied at different educational levels, including primary school (PS), junior high school (JHS), senior high school (SHS), and college, has the same effect size, indicating that PBL's influence on students' problem-solving skills is not affected by educational level. Heterogeneity across scientific disciplines ($Q < df$ and $P > 0.05$) does not indicate significant differences and has the same effect size. This means that the effect of PBL on problem-solving skills does not vary across science disciplines. These findings indicate that neither the level of education nor the science disciplines in PBL classes influences students' problem-solving skills. Therefore, PBL can be applied at all levels of education and in all scientific disciplines. However, based on individual studies at the class level, JHS ($P < 0.001$), SHS ($P < 0.001$), and science disciplines in the field of natural science ($P < 0.001$) show significant differences; this can occur due to differences in strategies or the presence of other variables that influence it.

Discussion

The researcher conducted a meta-analysis of 25 articles, with the highest frequency at the senior high school level (44%) and the most common field of study, natural science (36%). Based on effect-size calculations and forest-plot analysis, a summary effect size of 1.33 is obtained. This indicates that learners utilising problem-based learning exhibit these skills for addressing science problems, with Cohen's U_3 (%) of 133%, which is categorized as very high. The results of this meta-analysis have positive implications for various educational issues today. That PBL is effective in improving science problem-solving skills can be one effort to enhance 21st-century skills, namely critical thinking and problem-solving. This is supported by Edens's (2000) finding that problem-based learning can equip learners to fulfil 21st-century skills. The next implication is that PBL can be integrated with various educational technologies, enabling continued problem-solving through PBL to keep pace with technological developments. In this era of society 5.0, teachers are required to master digital and creative skills to deliver learning in schools (Asih et al., 2022). In addition, PBL has been shown to improve various science-process skills that students need to support increased understanding of science (Kasuga et al., 2022). This can be one of the efforts to achieve 21st-century skills and student success in the learning process.

This supports the findings of Sari et al. (2021), who found that PBL significantly increases scientific problem-solving skills. The results of this meta-analysis are consistent with those of Siregar et al. (2022), who found that PBL is effective in improving students' problem-solving skills in physics at the high school level. However, this meta-analysis only examines the effectiveness of PBL in the physics branch. In contrast, the present study's meta-analysis shows its effectiveness for students' problem-solving skills across various fields of science and at different educational levels. This is the uniqueness of the present meta-analysis compared to previous PBL meta-analyses. Research by Pitaloka and Suyanto (2019), Simanjuntak et al. (2021), Yuberti et al. (2019), Argaw et al. (2017), Simone (2008), Aidoo et al. (2016), Surur et al. (2020), Mundilarto & Ismoyo (2017), J. Damayanti et al. (2021), Nantha et al. (2022), Sari et al. (2021), Santuthi et al. (2020), Simarmata & Sirait (2019), Sahyar & Fitri (2017), Chileya & Shumba (2020), Akınoğlu & Tandoğan (2007), Jandrić et al. (2016), Tsai & Tang (2017) get a high effect size value. While research by Sahin (2010), Bilgin et al. (2009), Çeliker & Dere (2022), and M. Damayanti & Jirana (2022) has a moderate effect size, namely with effect size values of 0.275, 0.284, 0.377, and 0.366, respectively. Meanwhile, research by Anazifa & Djukri (2017) and Fauziah et al. (2014) reported small effect sizes of 0.019 and 0.081, respectively. The limited number of studies necessitated a test for publication bias. The funnel plot showed an asymmetry; hence, the Begg-Mazumdar test was used and obtained a result of ($p > 0.05$), indicating that there is no publication bias in this study. which indicates that the PBL effect on students' science problem-solving skills at certain levels of education and in certain fields of science is of high magnitude. The application of PBL across various scientific disciplines is more effective than that of conventional learning models. Problem-based learning trains students to work together in groups according to their respective roles, so that they are responsible for the knowledge they gain (Torres et al., 2022).

The results of this meta-analysis support the findings of all the studies included. This has been researched by Simarmata & Sirait (2019), who state that PBL improves students' skills in solving problems related to momentum and impulse material (physics). Physics subjects rely on students' problem-solving skills in a structured manner, so productive learning is needed at the secondary and higher education levels (Pelobillo, 2022). Between the experimental group using problem-based learning and the non-PBL group, there are disparities in the ability to solve chemical problems (Valdez & Bungihan, 2019). Problem-based learning demands student activity to increase student creativity in solving problems (Pitriah et al., 2018). Similar results were obtained by M Damayanti and Jirana (2022) in their research, which found that PBL could enhance students' capacity to solve science-related problems. In general, the studies in this meta-analysis only address the application of PBL in certain branches of science and at certain educational levels. Therefore, future PBL studies are needed to demonstrate its effectiveness in improving students' problem-solving skills through comprehensive research across various educational levels. Thus, a clearer picture will emerge of the efforts to train students' problem-solving skills appropriately. Through problem-based learning, students' problem-solving skills can be effectively developed. This aligns with research by Akınoğlu & Tandoğan (2007), which shows that PBL can train problem-solving skills. In addition, PBL learning requires expertise in resources, so teachers must be able to maximize student learning, especially in terms of learning time (Magaji, 2021). The problem-based learning approach successfully fosters a positive atmosphere that encourages student engagement. Research by Surur et al. (2020) suggests that students can improve problem-solving skills through PBL. The application of PBL results in significant improvements in students' problem-solving abilities (Sahyar & Fitri, 2017). Based on research by Çeliker & Dere (2022), student learning outcomes are improved compared to previous PBL implementations. The goal of the PBL model is to foster learning so that students can develop their problem-solving abilities (Sofyan et al., 2017). Anazifa & Djukri (2017) found that implementing problem-based learning enhanced students' problem-solving skills. According to Nantha et al. (2022), students in PBL and non-PBL classes differ in their science problem-solving abilities.

The implementation of PBL at the primary and junior high school levels yielded moderate effect sizes of 0.62 and 0.63, respectively. Meanwhile, at the senior high school and college levels, the effect sizes were very high, namely 1.35 and 1.82. Across educational levels, the overall effect size is 0.87 in the high category. The effect size obtained in the natural science discipline was in the medium category (0.66), while in the physics, biology, chemistry, and ICT disciplines, it was in the very high category (1.09, 1.00, 1.13, and 6.56, respectively). Overall, the effect size based on differences in scientific disciplines is in the medium category, namely 0.77. These results show that PBL across various levels of education and science disciplines is effective in improving students' science problem-solving skills compared to conventional instruction. Based on the heterogeneity test, differences in education levels and science disciplines between PBL and conventional classes were not significant ($p > 0.05$), indicating that these factors do not affect students' science problem-solving skills. Therefore, it is recommended to conduct further studies and analyses of the factors that influence students' problem-solving skills during PBL, such as motivation and self-confidence. Current trends in PBL research focus on the factors influencing the dependent variables measured in this study. Research by Suratno et al. (2020) shows that implementing the PBL model influences students' higher-level thinking abilities and learning motivation. In addition, research by Surur and Tartilla (2019) shows that applying PBL to students with high motivation yields the highest problem-solving abilities.

Conclusion and Implications

The meta-analysis revealed notable differences in problem-solving abilities between students in the experimental group who used problem-based learning and those in the control group who used non-PBL models. According to the forest plot analysis, the summary effect size is 1.33, indicating that students who use problem-based learning have 133% better problem-solving abilities than those who do not. This meta-analysis of the effect of PBL on students' problem-solving skills has a unique feature that distinguishes it from other studies. This study summarizes the effect of PBL on students' problem-solving skills at various levels of education, from elementary school to university, across various fields of science. The results of this study can guide educators in improving students' science problem-solving skills to achieve educational goals and support student success. The fail-safe N approach, the trim-and-fill method, and the Begg-Mazumdar test were used to assess publication bias, and the results indicated no publication bias in the researchers' meta-analysis. Thus, the conclusion that problem-based learning is more effective than the non-PBL model is unbiased. Based on the moderator test results for educational level ($P > 0.005$) and scientific discipline ($Q < df$; $P > 0.005$), there is no significant interaction, indicating that the effect of PBL on problem-solving skills is not influenced by educational level or scientific discipline. Therefore, PBL is effectively applied across all levels of education and in all scientific disciplines to improve problem-solving skills. However, PBL has its limitations; it can hamper its effectiveness in developing problem-solving skills among students with low motivation and self-confidence. Teachers must understand that each student has a different way of learning; they can combine PBL with other models. In addition, it is also recommended to conduct more empirical studies on the application of PBL to facilitate meta-analysis in science learning, especially regarding factors that influence students' problem-solving skills. Therefore, the author recommends conducting further empirical studies on other variables that influence students' problem-solving skills through PBL.

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