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Cross-disciplinary effects of problem-based learning on problem-solving skills in mathematics and beyond: A comprehensive meta-analysis and bibliometric

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Abstract

In the 21st century educational landscape, problem-solving has emerged as a fundamental competency across disciplines. Problem-based learning (PBL), rooted in constructivist pedagogy, has gained considerable attention for its potential to enhance students' cognitive engagement and practical application of knowledge. This study aims to comprehensively examine the effects of PBL on cross-disciplinary problem-solving skills, particularly in mathematics and other fields, through an in-depth meta-analysis and bibliometric visualization. The study employs a combined design of meta-analytic and bibliometric methods. The inclusion criteria for the meta-analysis are as follows: (1) relevant topic; (2) articles must be published in reputable indexed scientific journals; (3) provide effect size in the form of t-test, r, or F statistics; (4) minimum N of 20; (5) articles must be written in an internationally recognized language, namely English; and (6) published between 2012 and 2025. Articles were obtained from reputable databases such as Scopus, Web of Science, ERIC, and Google Scholar. This study used the JASP application for meta-analysis and the Publish or Perish and VOSviewer applications for bibliometric analysis. The findings indicate that: (1) bibliometric visualization highlights problem-solving, critical thinking, and self-efficacy as the main focuses influenced by learning context, teaching strategies, cognitive styles, and STEM approaches, which together form a complex interconnection in enhancing student learning achievement; and (2) research data were proven to be heterogeneous with a large effect size category and no indication of publication bias, indicating that the results of PBL interventions consistently have a strong impact on problem-solving skills. Therefore, the implementation of PBL is highly recommended as an effective strategy to significantly enhance students' problem-solving skills. This study uniquely combines meta-analysis and bibliometric mapping to provide a comprehensive cross-disciplinary evaluation of PBL's impact on problem-solving skills. This study provides strong empirical support for the effectiveness of PBL in enhancing students' problem-solving skills across disciplines, offering practical insights for educators and guiding future educational research and policy.

Keywords: problem-based learning, problem-solving skills, mathematics, meta-analysis, bibliometric

INTRODUCTION

The 21st century is marked by complex global dynamics, demanding individuals to possess critical and creative thinking skills and the ability to solve problems effectively (Kim et al., 2019). These challenges encourage the world of education to not only focus on content mastery but also on the development of essential competencies that enable learners to adapt and innovate amid rapid changes (Calacar, 2020; Santos, 2017). Problem-solving skills are one of the key competencies every individual must possess to tackle real-life and workplace challenges (Aslan, 2021).

Problem-solving skills serve as a crucial foundation for developing students' critical thinking and independence (Simanjuntak et al., 2021). These skills enable students to find solutions and formulate problems, evaluate various alternative solutions, and

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Contribution to the literature

- This article synthesizes research on the cross-disciplinary impact of problem-based learning (PBL) on problem-solving skills through meta-analysis and bibliometric visualization to deepen theoretical understanding of its influence on critical thinking, cognitive engagement, and self-efficacy.
- The study is limited to original articles published between 2012 and 2025 with reported effect sizes in reputable indexed journals, ensuring methodological rigor while narrowing its generalizability.
- This meta-analytic and bibliometric approach contributes by mapping research trends, synthesizing evidence of PBL's effectiveness, and identifying its interconnected influence on teaching strategies, cognitive styles, and STEM approaches to support future interdisciplinary pedagogical practices and policies.

make logical and effective decisions. Students who possess these skills tend to be more confident, reflective, and resilient in facing challenges, both in academic contexts and daily life. They are capable of managing complex tasks independently and do not give up easily when confronted with obstacles (Kadir, 2023; Setiawati & Agoestanto, A., 2023). Conversely, a lack of problem-solving skills may cause students to struggle with understanding problems, rely heavily on teacher instructions, and lack cognitive flexibility. This can negatively impact their motivation and academic achievement (Anjelina et al., 2021; Marchy et al., 2022). Therefore, education systems need to create learning environments that foster exploration, reflection, and experimentation.

Modern education is required to adopt learning approaches that not only transfer knowledge but also encourage learners to think critically, collaboratively, and reflectively. One approach that has been recognized as effective in achieving these goals is problem-based learning (PBL). PBL is a learner-centered instructional method in which students are presented with complex real-world problems and are asked to find solutions through investigation, discussion, and reflection (Cahyadini et al., 2024; Gök & Boncukçu, 2023). Through PBL, learners not only acquire knowledge but also develop higher-order thinking skills, including problem-solving, teamwork, and effective communication (Bhary et al., 2023).

Various empirical studies have shown that PBL can improve students' problem-solving skills (Chairuddin & Farman, 2022; Eviliasani et al., 2022; Ningsih et al., 2023; Pratiwi et al., 2022). However, these findings are still scattered and not comprehensively structured. Some studies have demonstrated the effectiveness of PBL in enhancing problem-solving abilities across different educational levels and fields of study (Hongnapa et al., 2023; Juhari & Muthahharah, 2021; Kertiyani et al., 2022; Rindengan & Wenas, 2020). However, variations in research design, sample sizes, measurement instruments, and PBL implementation contexts may influence the results and conclusions drawn. Therefore, efforts are needed to integrate and systematically analyze these findings to obtain a more comprehensive picture of the impact of PBL on problem-solving skills.

Moreover, although PBL has been widely implemented and studied, there is still a lack of research that maps publication trends, authors, journals, and countries that dominate research on PBL and problem-solving. Bibliometric analysis can provide information on the development of PBL research, collaboration among researchers, and the identification of emerging topics. Furthermore, through meta-analysis, it is possible not only to determine whether PBL is effective but also to assess the extent of its effectiveness depending on moderator variables such as educational level, field of study, assessment method, or duration of intervention. The urgency of this research lies in the need to integrate empirical findings on the effectiveness of PBL on problem-solving skills through meta-analysis, as well as to map the landscape of PBL and problem-solving research through bibliometric analysis.

Based on the above discussion, this study aims to:

(1) identify publication trends, authors, journals, and countries that dominate research on PBL and problem-solving and

(2) quantitatively analyze the impact of PBL on problem-solving skills through meta-analysis of selected studies.

LITERATURE REVIEW

Problem-Based Learning Model

PBL is a student-centered educational approach where learners confront real-world scenarios that require investigation and resolution, both individually and collaboratively. Rather than serving solely as a method for content delivery, PBL cultivates critical thinking, communication, and a sense of responsibility throughout the learning journey. Originally developed by Barrows and Tamblyn (1980) in the context of medical education to enhance diagnostic reasoning, this model has since found relevance across diverse disciplines, including the social sciences and primary education.

Numerous academic inquiries underscore the value of PBL in fostering dynamic and engaging learning

environments. Particularly in higher education, it prompts students to explore concepts independently, formulate hypotheses, and derive conclusions grounded in empirical data (Hmelo-Silver, 2004). The integration of digital media–such as simulations and augmented reality–has further strengthened knowledge construction by offering immersive and contextualized learning experiences (Hung, 2011).

Beyond cognitive development, PBL supports the cultivation of soft skills like leadership, empathy, and time management. Students work in teams, assume various roles, and strategize collectively, thereby mirroring professional problem-solving scenarios. When combined with interdisciplinary learning frameworks, PBL proves highly effective in bridging theoretical knowledge with practical application (Savery, 2006).

Problem-Solving Skills

In the context of 21st century education, problem-solving skills are viewed as essential indicators of student achievement. These abilities encompass identifying challenges, analyzing relevant data, developing potential solutions, and assessing the viability of selected strategies. According to Jonassen (2000), effective problem-solving is shaped not only by conceptual understanding but also by individual experiences, situational factors, and cognitive flexibility.

Within academic settings, these competencies are often nurtured through project-based tasks, case studies, and challenge-based learning activities. Research consistently highlights PBL as a productive avenue for enhancing such skills, as it fosters deep reflection, promotes analytical thinking, and encourages learners to evaluate multiple pathways before arriving at well-informed decisions (Belland et al., 2009).

In today's digital landscape, problem-solving extends beyond logical reasoning to include information literacy and digital fluency. Students are expected to critically evaluate sources, extract pertinent information, and leverage technology to optimize their problem-resolution process. Consequently, merging PBL with educational technology is considered a strategic response to preparing graduates who can adapt and respond creatively to global and professional complexities (OECD, 2015).

METHOD

Research Design

This study employed a mixed-methods design combining meta-analysis and bibliometric approaches to provide a comprehensive understanding of the impact of PBL on problem-solving skills. The meta-analysis was conducted to collect and analyze quantitative data from various relevant empirical studies, calculating the effect size to determine the extent to which PBL enhances students' problem-solving abilities. Meanwhile, the bibliometric method was used to map global research trends through metadata analysis of scientific publications from reputable databases. This analysis includes identifying the most productive authors, leading journals, top countries, and collaboration maps among researchers. The synergy between these two methods provides complementary analytical strength: bibliometrics maps the scientific landscape, while meta-analysis examines empirical effectiveness in depth.

Eligibility Criteria

In selecting articles for analysis, inclusion and exclusion criteria were applied to ensure the research findings were valid, relevant, and systematically comparable. These criteria were primarily used in the meta-analysis stage, while for bibliometrics, the focus was on the completeness of publication metadata. The inclusion criteria for the meta-analysis study were:

(1) relevant topic,
(2) articles must be published in indexed and reputable scientific journals,
(3) provide effect sizes in the form of t-tests, r, or F,
(4) minimum N of 20,
(5) articles written in an internationally recognized language, namely English, and
(6) published between 2012 and 2025.

The exclusion criteria included:

(1) review articles, meta-analyses, opinion pieces, editorials, or non-empirical reports,
(2) articles that do not directly investigate problem-solving skills as the dependent variable,
(3) studies not using PBL as the primary intervention,
(4) lack of adequate quantitative data to calculate effect size,
(5) sample size below 20, and
(6) articles not available on full-text or not publicly accessible.

Data Collection Technique

This study used the JASP application for meta-analysis and Publish or Perish and VOSviewer for bibliometric analysis. JASP was utilized to calculate effect sizes, test data heterogeneity (via Q-test and I^2), and identify potential publication bias using funnel plots and Egger's test. Meanwhile, Publish or Perish was used to gather publication metadata from various databases such as Google Scholar and Scopus, and this data was further analyzed using VOSviewer. VOSviewer was used to visualize author collaboration maps, keyword frequencies, and citation relationships among publications.

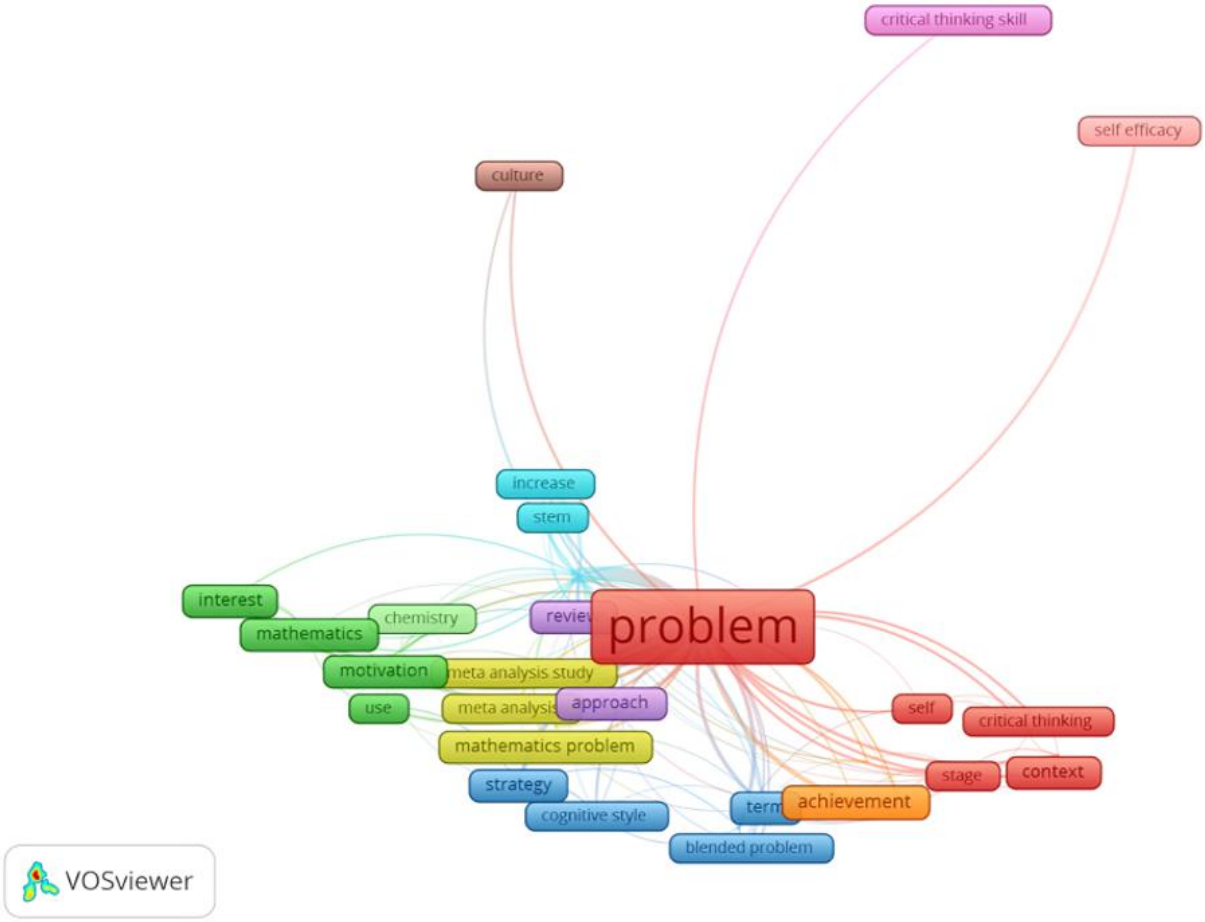

Figure 1. Trends based on fields of study clusters (Source: Authors' own elaboration)

Article searches used combinations of keywords: ("Problem-Based Learning" OR "PBL") AND ("Problem Solving Skills" OR "Problem Solving Ability") AND (impact OR effect OR influence). Boolean operators were used to ensure broader and more relevant search results. Articles were sourced from reputable databases such as Scopus, Web of Science (WoS), Index Copernicus, EBSCO, and SINTA to capture both primary scientific literature and grey literature. Scopus and WoS represent international indexing platforms for high-impact scientific publications. Index Copernicus and EBSCO provide access to multidisciplinary scholarly resources, including peer-reviewed journals and academic databases. SINTA (Science and Technology Index) is an official indexing platform developed by the Ministry of Education, Culture, Research, and Technology of Indonesia. SINTA is widely recognized for measuring the visibility, citation, and reputation of Indonesian journals, serving as a national benchmark for journal quality. Articles meeting the inclusion and exclusion criteria were then quantitatively analyzed in the meta-analysis.

Data Analysis Technique

The meta-analysis data analysis technique involved calculating effect sizes from each selected study, then analyzing them using a fixed or random effects model depending on the level of heterogeneity measured via Q-test and I^2 statistic. The analysis was complemented with publication bias tests using funnel plots and Egger's test, and exploration of moderator variables through subgroup analysis or meta-regression. Meanwhile, the bibliometric analysis was conducted using co-occurrence techniques to identify frequently co-appearing keywords, co-authorship to assess collaboration among authors, and citation analysis and bibliographic coupling to map the interrelationships and influence among publications, all visualized using VOSviewer.

THE RESEARCH RESULTS AND DISCUSSION

Trend of Problem-Based Learning Impact on Problem-Solving Skills

The following is a bibliometric visualization generated using VOSviewer software. This visualization maps the relationships among keywords frequently appearing in scientific publications on problem-solving. Each color represents a cluster of related topics, while the size and thickness of lines indicate the strength of connections between terms. This visualization provides an initial overview of the focus and direction of research trends in education and PBL.

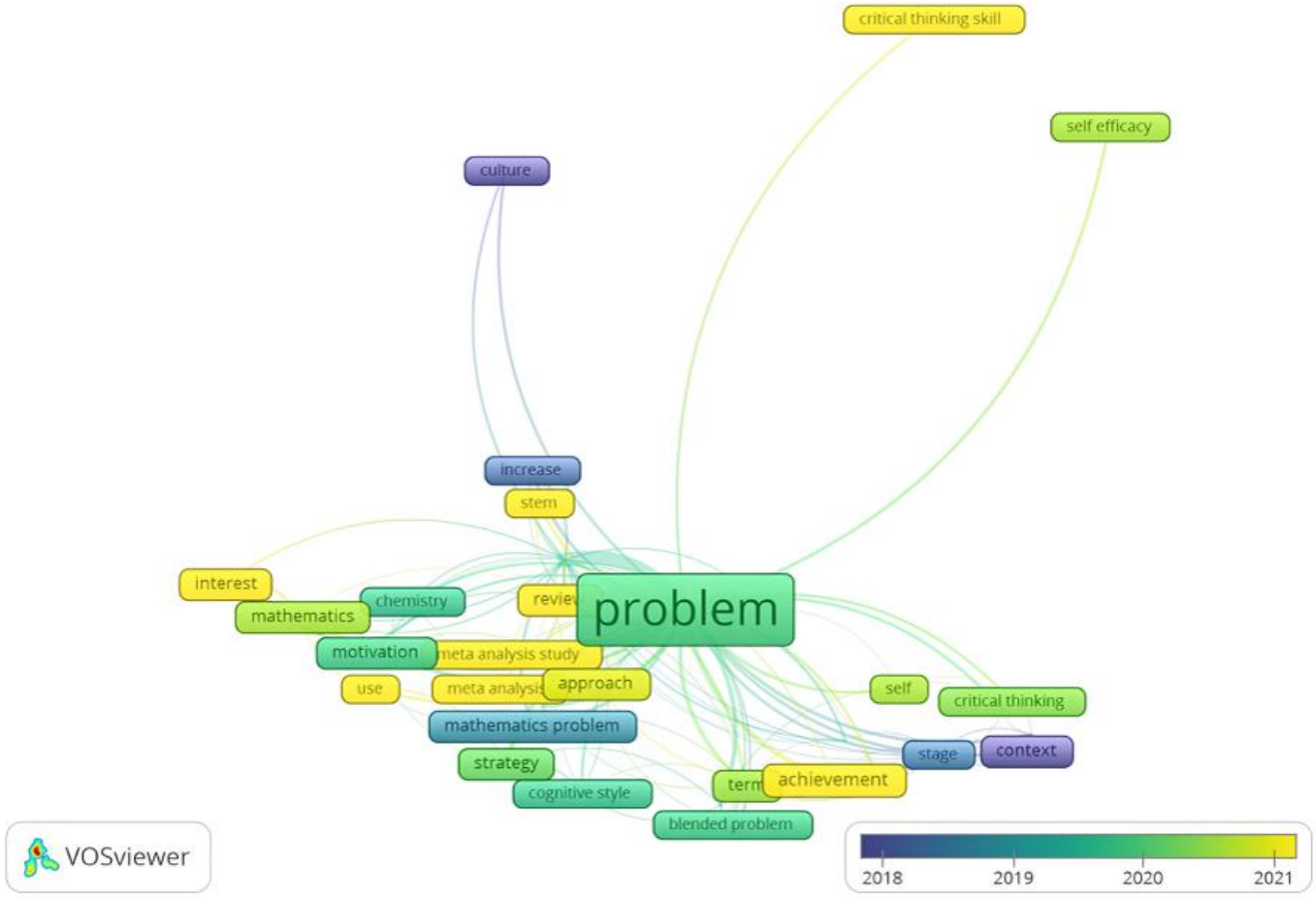

Figure 2. Trends by year (Source: Authors' own elaboration)

The bibliometric visualization in **Figure 1** shows that the red cluster is the focal point, with the main focus on topics such as problem-solving, critical thinking skills, and self-efficacy. The word "problem" is the central node linking various key terms like achievement, context, critical thinking, and self. Research in this cluster typically highlights the relationship between critical thinking abilities and self-efficacy in solving problems, which directly impacts learning achievement. Additionally, the emergence of terms like stage and context suggests that researchers are also considering specific phases and situations in the processes of critical thinking and problem-solving.

On the other hand, the yellow and blue clusters support the red cluster by adding dimensions of learning strategies and cognitive styles. The yellow cluster emphasizes topics such as achievement, strategy, and blended problems, indicating the importance of structured instructional approaches in achieving optimal learning outcomes. Meanwhile, the blue cluster brings in STEM issues and cognitive style, highlighting the importance of individual cognitive characteristics and interdisciplinary approaches in supporting problem-solving abilities. This overall pattern suggests that the development of critical thinking and problem-solving skills cannot be separated from learning context, teaching strategies, and learner characteristics.

The research focuses on this visualization centers on problem-solving associated with critical thinking skills and self-confidence. Learning context and teaching strategies serve as key supports in developing learning achievement. The role of cognitive styles, STEM approaches, and cultural aspects further enrich the complexity of the issues being studied.

Figure 2 is a bibliometric visualization based on a temporal analysis of keywords frequently appearing in problem-solving themed research, visualized using VOSviewer. The color of each keyword represents the dominant year of its appearance: darker (bluish) colors indicate older research trends (around 2018), while lighter (yellow) colors indicate newer trends (around 2021).

From the visualization, it can be seen that earlier research focus (2018-2019) was largely associated with keywords such as culture, increase, STEM, strategy, and meta-analysis. This suggests that during those years, studies were more directed towards general approaches, cultural influences, and literature review methods in the context of problem-solving. Meanwhile, more recent topics (2020-2021) began shifting toward critical thinking skill, self-efficacy, achievement, and context. This

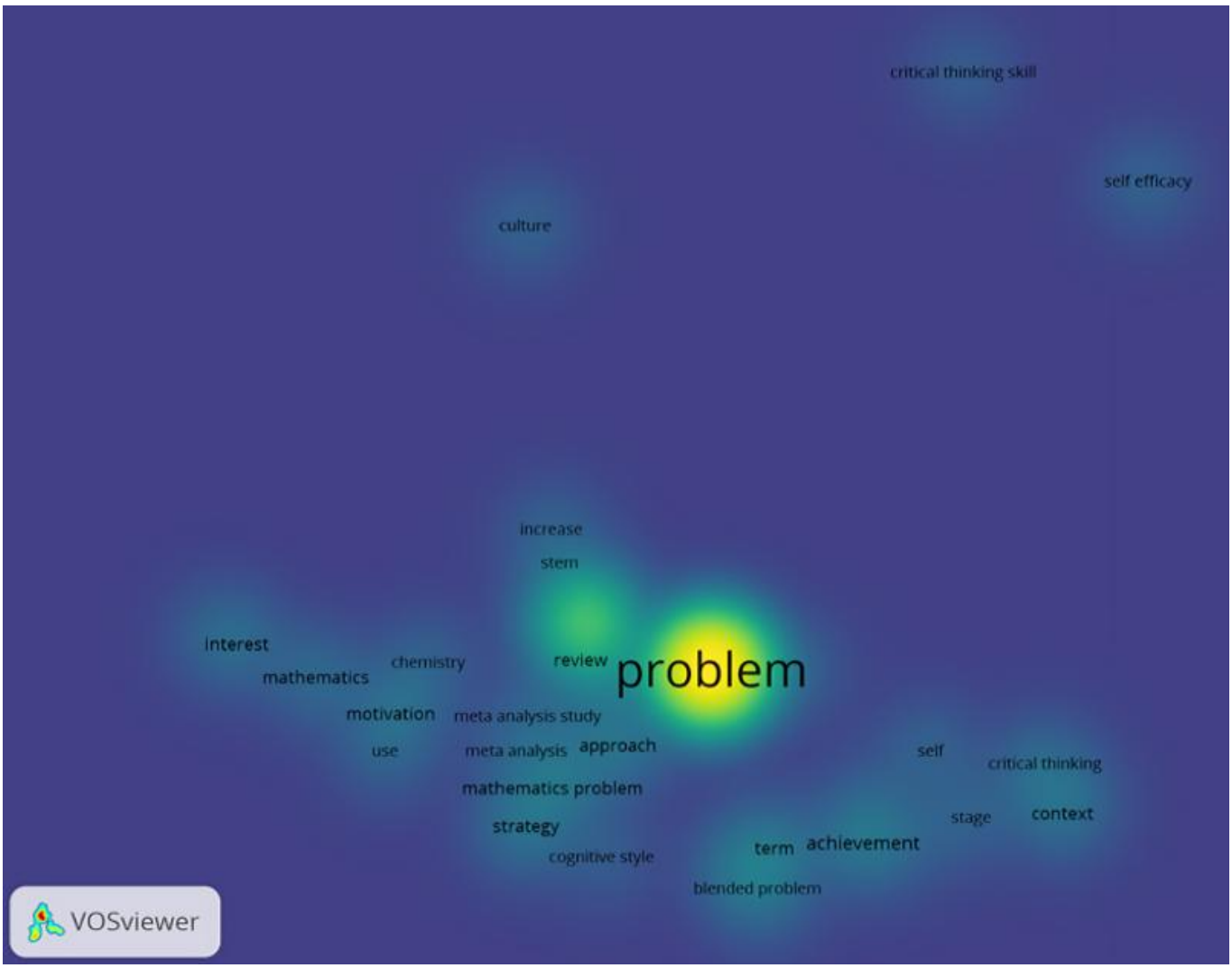

Figure 3. Trends by discussed topics (Source: Authors' own elaboration)

reflects an increasing interest in the psychological and contextual dimensions of problem-solving, aligning with 21st century education needs to foster higher-order thinking skills and learner confidence.

Figure 3 shows the bibliometric visualization result based on the density view of keywords in problem-solving themed research, created using VOSviewer. The colors in this visualization indicate the density or frequency of keyword appearances in the analyzed dataset. Bright (yellow) areas indicate the most frequently researched topics, while darker areas (blue to purple) represent rarely studied topics and potential research gaps.

From the visualization, it is evident that keywords such as problems, review, achievement, approach, and mathematics problems are the most dominant and frequently appearing topics in prior research. On the other hand, topics like critical thinking skill, self-efficacy, culture, cognitive style, and blended problem are located in darker areas, indicating that the frequency of research on these themes remains low. This shows that these topics have great potential for further study in the future, especially in the context of education and the development of higher-order thinking skills.

The above research results show that problem-solving research does not stand alone but is strongly correlated with the strengthening of higher-order thinking skills. This aligns with Patunah et al. (2024), who emphasized that critical thinking is a core component in the problem-solving process, as it requires students to analyze situations, evaluate information, and make logic-based decisions. Additionally, McLeod (2016), through the theory of self-efficacy, explained that an individual's belief in their own ability significantly influences learning outcomes and problem-solving capability. This reinforces findings that 21st century education demands the strengthening of soft skills, including self-efficacy, creativity, and critical thinking, to address the complex challenges of the future (Martaningsih et al., 2022; Polat & Özkaya, 2023; Yapatang & fon Polyiem, 2022). This indicates that the academic world is beginning to shift its focus from content-based approaches to those more centered on the holistic development of student potential.

Table 1. Data recapitulation of the 38 reviewed articles

No	Reference	N	r	t	F	Subject	Country	Index
1	Chang et al. (2012)	80			36.670	Elementary school	Taiwan	Scopus Q1
2	Aslan (2021)	45			19.770	University	Turkey	Scopus Q1
3	Argaw et al. (2017)	81		7.518		Senior high school	Ethiopia	Scopus Q2
4	Shongwe (2024)	86		4.970		Senior high school	South Africa	Scopus Q2
5	Polat and Özkaya (2023)	48		2.050		Junior high school	Turkey	Scopus Q3
6	Kadir (2023)	163		8.759		Senior high school	Indonesia	Scopus Q3
7	Widyaningtyas et al. (2024)	120	0.870			Senior high school	Indonesia	Scopus Q3
8	Knöpfel et al. (2024)	91		4.080		University	Germany	Scopus Q3
9	Dorimana et al. (2022)	82		12.080		Senior high school	Rwanda	Scopus Q4
10	Siagian et al. (2019)	58	0.875			Junior high school	Indonesia	Scopus Q4
11	Yapatang and fon Polyiem (2022)	20		39.280		Junior high school	Thailand	Scopus Q4
12	Martaningsih et al. (2022)	60		2.704		Elementary school	Indonesia	Scopus Q4
13	Simanjuntak et al. (2021)	192	0.986			Senior high school	Indonesia	WoS ESCI
14	Hobri et al. (2020)	68			21.368	Junior high school	Indonesia	WoS ESCI
15	Sari et al. (2021)	62			25.011	University	Indonesia	WoS ESCI
16	Asdar et al. (2023)	48	0.812			Junior high school	Indonesia	Proc. Scopus
17	Juhari and Muthahharah (2020)	33		3.180		Senior high school	Indonesia	Proc. Scopus
18	Rindengan and Wenas (2020)	60	0.837			Junior high school	Indonesia	Proc. WoS
19	Pohan et al. (2020)	50			29.510	Elementary school	Indonesia	IC
20	Macapayad (2025)	232	0.497			Junior high school	Philippines	IC
21	Hidayat and Taufiqurrahman (2022)	53		2.689		Junior high school	Indonesia	IC
22	Arbo and Ching (2022)	40	0.277			Junior high school	Philippines	IC
23	Azizah et al. (2023)	26	0.937			Senior high school	Indonesia	EBSCO
24	Kertiyani et al. (2022)	71	0.517			Junior high school	Indonesia	EBSCO
25	Treepob et al. (2023)	32		4.620		Junior high school	Thailand	EBSCO
26	Patunah et al. (2024)	66	0.815			Junior high school	Indonesia	SINTA 2
27	Pratiwi et al. (2022)	34	0.303			Elementary school	Indonesia	SINTA 2
28	Eviliasani et al. (2022)	30		4.177		Junior high school	Indonesia	SINTA 2
29	Anjelina et al. (2021)	25		27.096		Senior high school	Indonesia	SINTA 2
30	Bhary et al. (2023)	30		3.830		Junior high school	Indonesia	SINTA 2
31	Chairuddin & Farman (2022)	51		0.240		Junior high school	Indonesia	SINTA 2
32	Cahyadini et al. (2024)	54			92.792	Senior high school	Indonesia	SINTA 2
33	Tampubolon and Sipahutar (2024)	50		10.706		University	Indonesia	SINTA 2
34	Gök and Boncukçu (2023)	114			51.300	Junior high school	Turkey	SINTA 2
35	Ningsih et al. (2023)	70		2.753		Senior high school	Indonesia	SINTA 2
36	Setiawati and Agoestanto (2023)	50	0.575			Senior high school	Indonesia	SINTA 3
37	Marchy et al. (2022)	32		11.804		Junior high school	Indonesia	SINTA 4
38	Muzakkir (2021)	34	0.765			Senior high school	Indonesia	SINTA 4

Note. IC: Index Copernicus

Problem-Based Learning Impact on Problem-Solving Skills

This study reviews various empirical studies evaluating the effectiveness of educational interventions through a meta-analytical approach. Data were obtained from 38 articles published between 2012 and 2025, covering various educational levels, countries, and reputable journal indexations. The analysis focused on sample size (N), effectiveness values (r, t, F), as well as geographic contexts and school levels to assess the consistency and strength of the examined interventions (**Table 1**).

Before estimating the average effect, it is important to test for heterogeneity among the studies analyzed. Heterogeneity indicates the extent to which differences in study results are due to actual variation rather than mere sampling error. Therefore, the residual heterogeneity analysis and meta-analytic estimates are presented to provide an overview of the level of variation and overall effect reliability (**Table 2**).

Table 2. Residual heterogeneity test

Q_e	df	p
923.943	37	< .001

The residual heterogeneity test result shows a Q_e value of 923.943 with 37 degrees of freedom (df) and $p < .001$, indicating significant heterogeneity among studies. The I^2 value of 95.794% reinforces this finding, suggesting that approximately 96% of effect size variability across studies is due to actual differences rather than random error. The estimated combined effect size of 0.894 with a 95% confidence interval (CI) between 0.688 and 1.100 indicates a large and significant effect. However, the broader prediction interval (from -0.341 to

Table 3. Meta-analytic estimates

	Estimate	95% CI		95% PI	
		Lower	Upper	Lower	Upper
Effect size	0.894	0.688	1.100	-0.341	2.129
τ	0.601	0.486	0.802		
τ^2	0.361	0.237	0.643		
I^2	95.794	93.712	97.592		
H^2	23.775	15.904	41.531		

2.129) suggests that individual study effects may vary greatly, including the possibility of negative effects. The τ^2 value of 0.361 and τ of 0.601 indicate a relatively high level of actual variance between studies, underscoring the need for moderator analysis to understand the sources of this heterogeneity (**Table 3**).

A high level of heterogeneity in a meta-analysis suggests substantial differences in research design, sample characteristics, or intervention contexts among the analyzed studies. Such heterogeneity frequently arises in the field of education due to widely varying approaches, learning strategies, and student backgrounds (Yusuf & Fajari, 2022). According to Chamdani et al. (2022), high heterogeneity is not a weakness but an indication that effect sizes are not identical and are influenced by potential moderators that require further analysis. This opens up opportunities to conduct subgroup analysis or meta-regression to identify factors causing variations such as differences in education level, intervention duration, or types of instructional media used. Subsequently, an effect size test was conducted (**Table 4**).

Table 4. Pooled effect size test

Estimate	Standard error	t	df	p
0.894	0.102	8.793	37.000	< .001

The result of the pooled effect size test shows that the estimated combined effect size is 0.894 with a standard error of 0.102, a t-value of 8.793, and $p < .001$, indicating high statistical significance. These results demonstrate that the intervention or variable analyzed has a strong and consistent influence on the outcomes measured in the studies included in this meta-analysis. Compared with Cohen's d guidelines for interpreting effect sizes, the value of 0.894 falls into the large effect category, meaning that the interventions or treatments in these studies have a substantial practical impact. Furthermore, a forest plot was used to visualize the effect size of each study in the meta-analysis, as well as the overall pooled estimate (**Figure 4**).

The study results show a large effect size (**Table 5**). This magnitude of effect is strong evidence that the

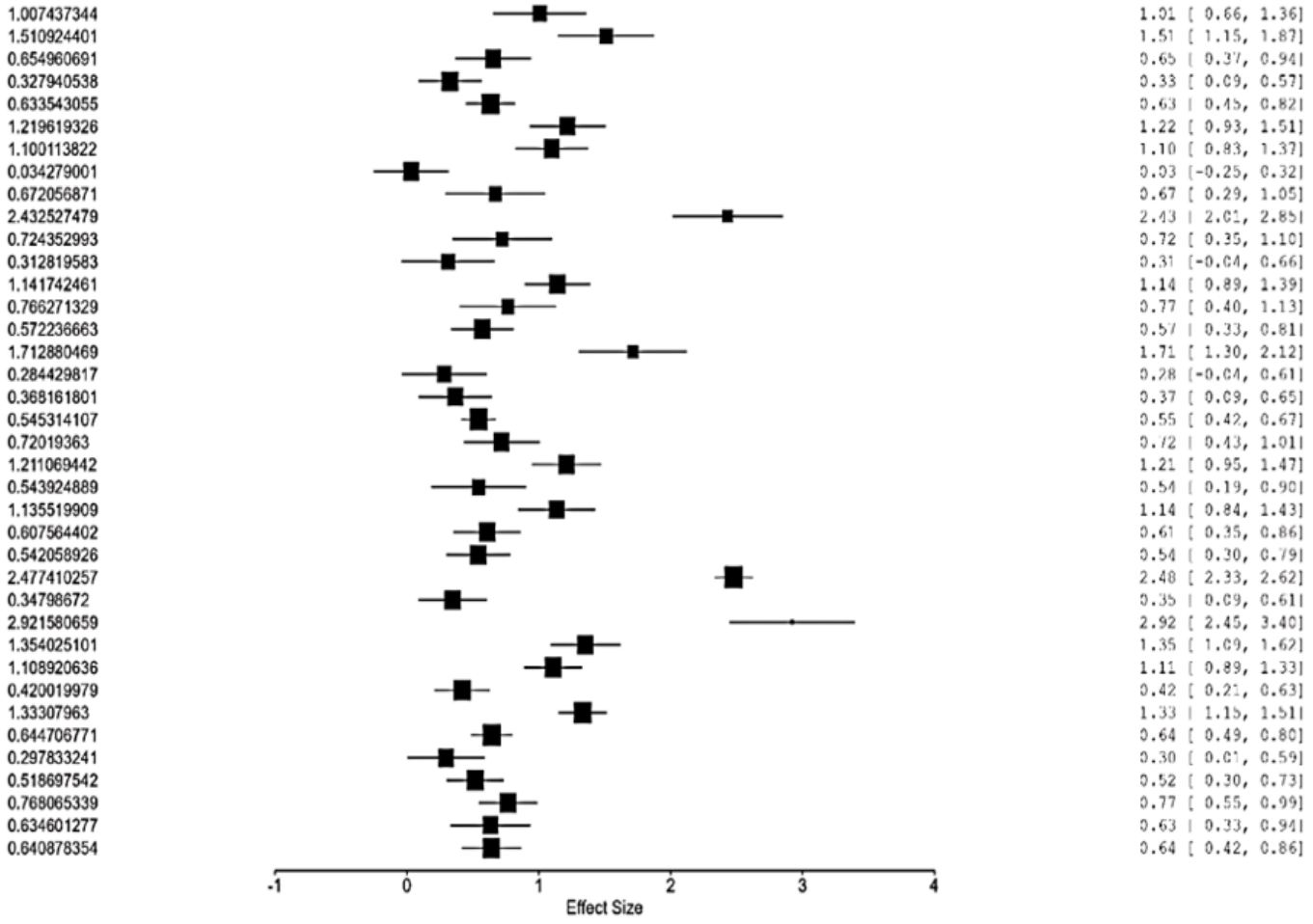

Figure 4. Forest plot (Source: Authors' own elaboration)

Table 5. Test of effect

	t	df	p
PET	2.995	36	0.005

Table 6. Test of publication bias

	t	df	p
PET	-0.388	36	0.701

Table 7. PET-PEESE mean estimates (μ)

	Estimate	Standard error	t	df	p	95% CI	
						Lower	Upper
PET	1.020	0.341	2.995	36	0.005	0.353	1.687
PEESE	0.876	0.192	4.567	36	< .001	0.500	1.252

observed improvement in skills is not coincidental but a real impact of the applied learning strategies (Hernandez et al., 2020). Research by Siagian et al. (2019) also supports the view that instructional strategies requiring students to actively think and solve problems–such as PBL–often result in large effects, especially in developing higher-order thinking skills. PBL has a very significant influence on students' problem-solving skill development (Dorimana et al., 2022). Students are presented with real-world situations or problems that require them to actively and independently identify, analyze, and find solutions. This process fosters critical, analytical, and creative thinking abilities essential for solving problems (Knöpfel et al., 2024; Shongwe, 2024). Through PBL, students do not simply receive information passively but are engaged in exploring and reflecting on complex issues. This encourages students to develop systematic thinking strategies, hone their ability to evaluate alternative solutions, and strengthen their mental resilience in facing challenges (Argaw et al., 2017; Chang et al., 2012; Widyaningtyas et al., 2024).

To assess the potential for publication bias in a meta-analysis (**Table 6**), the precision effect test and precision effect estimate with standard error (PET-PEESE) (**Table 7**) are often used as more sensitive and corrective regression methods. These methods have the advantage of estimating the true effect by adjusting for potential bias caused by small sample sizes. Additionally, PET-PEESE provides more stable estimates compared to visual approaches such as funnel plots.

The results of the effectiveness test using the precision effect test showed a t-value of 2.995 with p = 0.005, indicating a statistically significant effect. The publication bias test using the precision effect test produced a t-value of -0.388 with p = 0.701, meaning there was no significant indication of publication bias. The mean effect estimate from the precision effect test was 1.020 with a 95% CI ranging from 0.353 to 1.687. Meanwhile, the precision effect estimate with standard error provided an effect estimate of 0.876 with a 95% CI between 0.500 and 1.252, also showing a significant result. Overall, this data indicates that no publication bias was detected in the conducted meta-analysis.

Yang and Berdine (2021) emphasize that the absence of publication bias enhances the credibility of using meta-analysis results for policy practices and educational planning. These findings suggest that the analyzed research outcomes are not solely from studies with positive results but also include studies with neutral or even negative findings. Therefore, the conclusions drawn from this meta-analysis are not distorted by publication selectivity but rather reflect the empirical situation in a comprehensive manner.

CONCLUSION

Based on the results and discussion, the following conclusions can be drawn:

1. The bibliometric visualization highlights problem-solving, critical thinking, and self-efficacy as the main focal points influenced by learning contexts, teaching strategies, cognitive styles, and STEM approaches, which together form a complex interrelation in enhancing student learning achievement.
2. The research data proved to be heterogeneous with a large category effect size, and no indication of publication bias was found, suggesting that PBL interventions consistently have a strong impact on problem-solving skills.

Therefore, the implementation of PBL is highly recommended as an effective strategy to significantly enhance students' critical thinking and problem-solving abilities.

This study revealed a relatively high degree of data heterogeneity, indicating that the effectiveness of PBL may vary depending on the context and characteristics of the learners. Additionally, the analyzed studies primarily focused on the cognitive domain, while affective and social aspects have not been deeply examined. The variation in methods and instruments used to measure problem-solving skills across studies also limits the generalizability of the findings. The dominance of research within STEM disciplines further reduces the representation of other fields. Lastly, limited access to publications in non-English languages potentially decreases the diversity of data sources.

Researchers are advised to conduct further studies using more uniform research designs and to consider affective and social dimensions in PBL. Education practitioners should adopt PBL strategies to suit the diverse characteristics of learners and learning contexts. Educational institutions should encourage cross-disciplinary collaboration, not only in STEM, to broaden

the understanding of this learning approach's effectiveness. Policymakers can support the development of flexible and inclusive curricula that accommodate various cognitive styles and innovative approaches. Furthermore, improving access to and support for publications and research in multiple languages can enhance the diversity and quality of research data.

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